Volume XXXII October, 1931 Number 4

SOIL SCIENCE

Editor-in-Chief
JACOB G. LIPMAN

Associate Editor
HERMINIE BROEDEL KITCHEN

Contents

The Fixation of Nitrogen by Leguminous Plants Under Bacteriologically Controlled Conditions. P. W. Wilson, E. W. Hopkins and E. B. Fred.. 251

Changes in Composition of Soybeans Toward Maturity as Related to Their Use as Green Manure. Wm. A. Albrecht and W. H. Allison..... 271

The Effects of Vegetation and Climate Upon Soil Profiles in Northern and Northwestern Wyoming. James Thorp..... 283

Soil Profile Studies: III. The Process of Podzolization. J. S. Joffe..... 303

Book Reviews..... 325

PUBLISHED MONTHLY
THE WILLIAMS & WILKINS COMPANY
MT. ROYAL AND GUILFORD AVENUES
Baltimore, Maryland, U. S. A.

Made in United States of America

SOIL SCIENCE

FOUNDED BY
RUTGERS COLLEGE
NEW BRUNSWICK, N. J.

ADVISORY STAFF

Prof. A. W. Blair, Dr. J. S. Joffe, Prof. L. L. Lee, Dr. H. C. McLean, Dr. S. Mattson, Prof. A. L. Prince, Dr. J. W. Shive, Dr. R. L. Starkey and Dr. S. A. Waksman, New Jersey Agricultural Experiment Station, New Brunswick, N. J.

CONSULTING EDITORS

DR. F. J. ALWAY
University of Minnesota, St. Paul, Minn.

PROF. K. ASO
Imperial University, Tokyo, Japan

PROF. C. BARTHEL
Central Agricultural Experiment Station, Experimentalfaltet, Sweden

DR. P. E. BROWN
Iowa State College of Agriculture, Ames, Iowa

PROF. DR. ALBERT DEMOLON
Ministry of Agriculture, Paris, France

DR. H. J. CONN
New York State Experiment Station, Geneva, N. Y.

DR. E. B. FRED
University of Wisconsin, Madison, Wis.

DR. J. E. GREAVES
Utah Agricultural College, Logan, Utah

DIRECTOR ACH. GREGOIRE
Agricultural Experiment Station, Gembloux, Belgium

DR. B. L. HARTWELL
26 Rowe St., Auburndale, Mass.

DR. D. J. HISSINK
Soil Science Institute, Groningen, Holland

DR. C. B. LIPMAN
University of California, Berkeley, Calif.

DR. BURTON E. LIVINGSTON
Johns Hopkins University, Baltimore, Md.

DR. T. L. LYON
Cornell University, Ithaca, N. Y.

DR. M. M. MCCOOL
Michigan State College, East Lansing, Mich.

DR. W. H. MACINTIRE
University of Tennessee, Knoxville, Tenn.

DR. E. A. MITSCHERLICH
University of Königsberg, Prussia

PROF. C. A. MOOERS
University of Tennessee, Knoxville, Tenn.

DR. SVEN ODÉN
Central Agricultural Experiment Station, Experimentalfaltet, Sweden

DR. THEO. REMY
Institut für Boden- und Pflansenbaulehre, Bonn a. Rh.

PROF. G. ROSSI
Royal Agricultural High School in Portici, Naples, Italy

DR. E. J. RUSSELL
Rothamsted Experimental Station, Harpenden, England

DR. O. SCHREINER
U. S. Department of Agriculture, Washington, D. C.

DR. ALEXIUS A. J. DE'SIGMOND
Royal Hungarian Joseph University of Technical Sciences, Budapest, Hungary

DR. J. STOKLASA
Technical High School, Prague, Czechoslovakia

PROF. CHAS. E. THORNE
Ohio Experiment Station, Wooster, Ohio

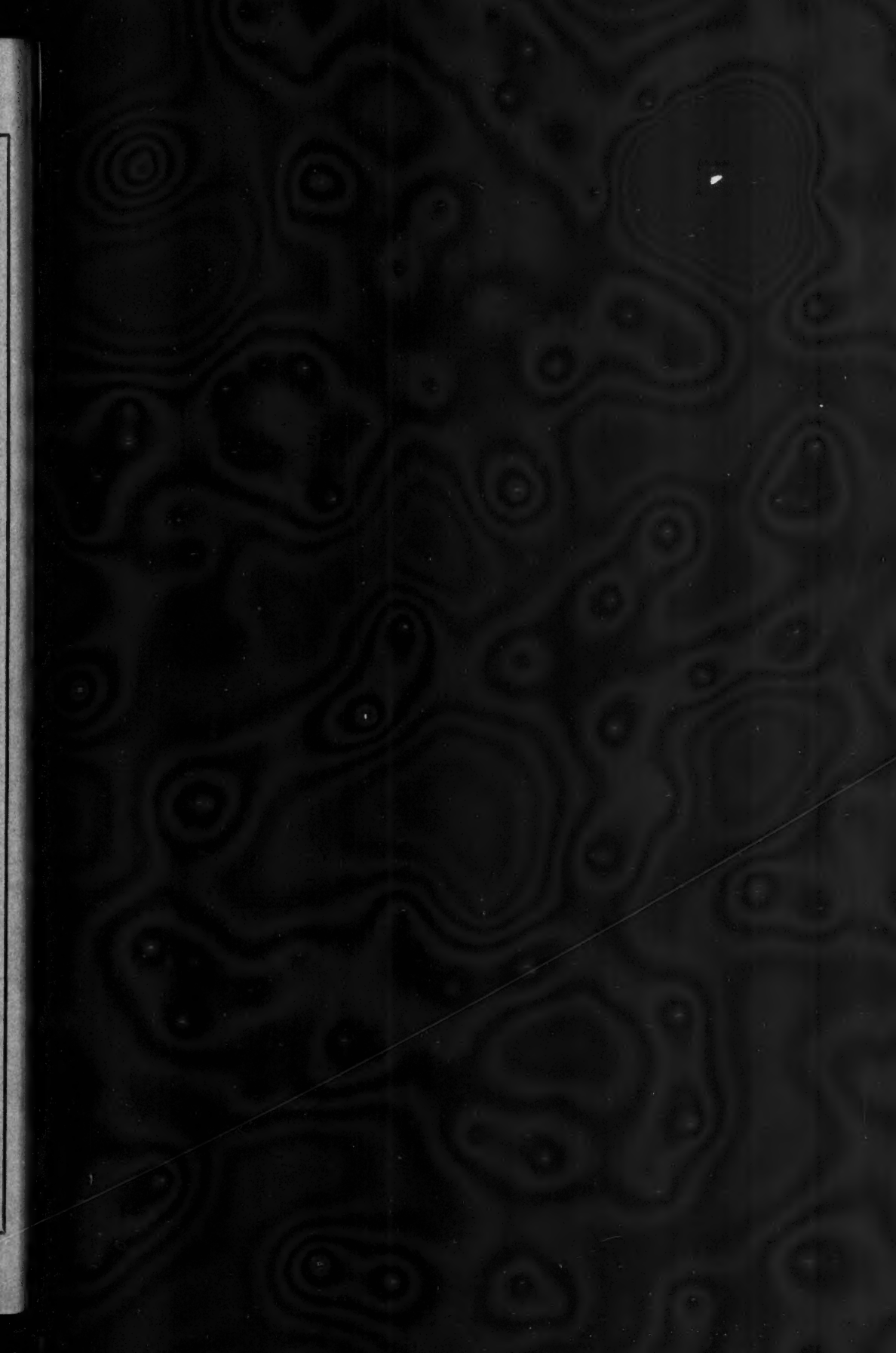
PROF. N. M. TULAIKOV
Agricultural Experiment Station, Saratov, U. S. S. R.

DR. F. WEIS
Royal Agricultural and Veterinary College, Copenhagen, Denmark

PROF. S. WINOGRADSKY
Pasteur Institute, Paris, France

Entered as second-class matter May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879.

Copyright, 1931, The Williams & Wilkins Company



THE FIXATION OF NITROGEN BY LEGUMINOUS PLANTS UNDER BACTERIOLOGICALLY CONTROLLED CONDITIONS[1]

P. W. WILSON, E. W. HOPKINS AND E. B. FRED

University of Wisconsin

Received for publication February 9, 1931

A study of the biochemistry of nitrogen fixation by the Leguminosae has been made possible by a grant from the Herman Frasch fund. This problem is characterized by a certain phenomenon, viz., the fixation of elemental nitrogen as a result of an association between certain bacteria and plants. This association effects a result which apparently neither member can produce alone. It is patent that any attack upon the question of what actually obtains in the fixation must have as a keystone, studies of the communal activities of the plant and bacteria. The history of scientific inquiry, however, teaches that a comprehension of the interaction of several components in a complex system is best achieved by analytical means. That is, a knowledge of the properties of each variable when isolated is always an aid, and frequently a necessity, for a successful attack on the complicated relationships existing in the system as a whole. Obviously, experiments directed toward an understanding of the processes involved in nitrogen fixation by the Leguminosae must be separated into two groups: (*a*) those concerned with the isolated components, particularly the bacterium, and (*b*) those concerned with the association of plant and microörganism. This partition of the research may give rise to investigations that apparently are only superficially connected. Thus a knowledge of the physiology of the causal organism is certainly germane to a complete understanding of the mechanism of the fixation, but studies in this direction possibly will lend a certain diffuseness to a series of researches that purport to deal only with the biochemistry of nitrogen fixation by the Leguminosae. However, as the work progresses, the relationship of the separate phases to the general project should become apparent and the desired unity achieved.

In this paper are reported results of experiments that deal with the fundamental problem of fixation by the host plant and bacteria. Considerations, to be discussed in detail later, indicated the desirability of an investigation of the behavior of the plant with the proper bacteria present under conditions which exclude the complications induced by the presence of other microör-

[1] Herman Frasch Foundation Research in Agricultural Chemistry, paper no. 17. Contribution from the departments of agricultural chemistry and agricultural bacteriology, University of Wisconsin.

ganisms. In many questions concerned with nitrogen fixation by leguminous plants, it is neither necessary nor desirable that the experiments be carried out under conditions which prevent the growth of foreign bacteria. If the results are to be applied to practical agriculture, the conditions of the experiments should simulate as closely as possible those prevailing in the field. But for problems of a more theoretical nature, it is indispensible that our attention be restricted to the most simple system possible, in order that the essential factors may be separated from the incidental ones. Specifically, we wish to ascertain whether nitrogen is fixed by legumes when only members of the Rhizobium species are present, and if so, the influence of other organisms on the fixation. A second problem considered in this paper is that which deals with the variability of nitrogen fixation by legumes inoculated with different strains of the proper organism, another instance in which freedom from contaminating forms is of utmost importance.

LITERATURE

The method used to grow the plants under bacteriologically controlled conditions has been described in a previous paper (14). Essentially it involved the growth of small seeded leguminous plants on an agar substrate in 12- and 32-ounce bottles protected from air contamination with cotton plugs. Once the method for growing plants free from microörganisms was selected, the question arose:—Will the conditions adopted as necessary to insure complete freedom from bacteria allow nitrogen to be fixed by the association of bacteria and plant? Therefore, our first experiments were devoted to the question of nitrogen fixation in agar.

The fixation of nitrogen under conditions which keep the plant roots submerged is disputed. Hiltner (11) states that although alder plants form nodules in water culture, the plants derive no benefit from the nodules. Nobbe and Hiltner (19) found that wild acacia attained better growth in water cultures when some of the nodules were exposed to air. Golding (6) attempted to verify this finding with peas. He found that a slight fixation of nitrogen took place in water cultures with the roots of the plants covered. Plants grown in water cultures, the surface of which was covered with oil, fixed no nitrogen. The fixation of nitrogen by plants with exposed roots, or with roots covered, but with air or oxygen passing through, was no greater than that fixed by plants, the roots of which were submerged. Harrison and Barlow (9) used a maltose-wood ash-agar substrate for growth of legumes and observed nodule formation on garden bean (*Phaseolus vulgaris*), hairy vetch (*Vicia villosa*), pea (*Pisum sativum*), and soybean (*Soja Max*). They reported that uninoculated plants became yellow and gradually withered as if from nitrogen starvation, whereas the inoculated plants thrived for as long as 5 months. Photographs of vetch (5 months) inoculated and uninoculated exhibited unmistakable evidence of benefit through inoculation, but peas 2½ months old showed very little benefit. Very likely this was due to the large food reserve

in the pea seed. There is no doubt that these experiments demonstrated the fixation of nitrogen in an agar substrate, but the actual quantities fixed are not given.

The only quantitative data from experiments in which agar was used are those given by Thornton (20). This worker claims that inoculated alfalfa grown in wide test tubes fixed nitrogen only when the nodules had access to air. Unfortunately the data in support of this claim are too meager to allow adequate judgment. Five tubes in which the nodules were exposed to the air had a mean total nitrogen content (agar plus plants) of 3.53 mgm.; four tubes in which the nodules were imbedded in the agar had a mean of 1.88 mgm.; the single control contained 2.26 mgm. of nitrogen. The nitrogen content of the tubes in which the nodules were exposed to the air was extremely variable, ranging from 2.63 to 4.22 mgm.; the amount fixed on the basis of the single control (the variability of which is of course not calculable) was 1.27 ± 0.330 mgm. The variability of the four tubes in which the nodules were imbedded in the agar was much less; the range was 1.55 to 2.06 mgm., but a nitrogen loss of 0.38 ± 0.11 mgm. was sustained. Both the gain and the loss of nitrogen are significant from a statistical point of view, and any theory based on these data should explain the loss suffered by the plants whose nodules were imbedded. The explanation in all likelihood lies in the single control; if more controls had been included, it is probable that the loss noted would have been within experimental error. It might be argued that data of so few samples cannot be treated in a statistical manner, but in that case sufficient samples should be taken to allow for the variability. The evidence presented by Thornton's photographs is more conclusive. The plants in which the agar is intact differ little from the controls, while those in which the agar has shrunk away from the sides of the test tubes show a marked improvement. Whether this shrinkage actually exposed the nodules to the air cannot be decided from the photographic data.

A second reason for the investigation of fixation in agar under bacteriologically controlled conditions was to shed light on the question of whether members of the root nodule bacteria are the sole organisms concerned in the fixation of atmospheric nitrogen by legumes. Observations tending to make some workers skeptical that this fundamental problem has been completely solved are: (*a*) reports of the presence of organisms other than rhizobia in nodules; (*b*) the difficulty of growing plants in the complete absence of contaminators from soil and air; and (*c*) the negative results obtained by numerous experimenters in regard to nitrogen fixation by rhizobia apart from the host plant [Hopkins (13), Löhnis (17), and Allison (1)]. It is commonly accepted that members of the genus *Rhizobium* are the sole causal organism concerned in the utilization of atmospheric nitrogen by legumes. Nevertheless, Beijerinck after 30 years' work in this field expressed doubt as to whether this had been demonstrated under experimental conditions that eliminated all other organisms. He says (2):

. . . . it proved hitherto impossible in sand cultures to bring Leguminosae to complete development by infection with *B. radicicola* only, and with the exclusion of all other microbes. Such experiments are at the end of the vegetation period rich in various other species, in particular in *B. fluorescens liquefaciens* and the nitrogen fixing spore former, *Cl. pasteurianum* and *Helobacter cellulosae*. This observation holds good as well for those experiments made by myself as for those of others, and this should never be lost sight of when reading descriptions of the infection experiments with so-called "pure cultures." It is a well-known fact that the Papilionaceae, when cultivated in liquid, do not fix the atmospheric nitrogen indifferently whether they produce tubercles or not.

EXPERIMENTAL

Methods

The technique used for growing the plants and testing the medium for contaminating forms has been described in a previous publication (14). Briefly, it consists in the sterilization of the seeds in a modified Dakin solution, the germination on sterile blotting paper, and the transfer of the seedling to a Crone-agar substrate in 12-ounce or 32-ounce bottles. This transfer is done in a special chamber so constructed as to eliminate contamination from the air. After growth of the plants, a test of the substrate is made for foreign organisms by making subcultures in litmus milk. In growing plants in the greenhouse, and especially in closed containers, it must be recognized that a highly artificial environment is forced upon the plant; a circumstance that must be considered in an interpretation of results. Care must be exercised to reduce as far as possible the effect of factors that are detrimental to the physiology of the plant. For example, during the months from December to March, there is a lack of sunlight in this latitude. Accordingly, artificial illumination by means of a battery of 200-watt Mazda lamps was employed during these months with apparent benefit to the growth of the plants. On the other hand, during the spring and summer months the plants must be protected from excessive illumination with resultant overheating. This was accomplished by placing the culture bottles in wet sand to the depth of the agar substrate; the use of fans to increase circulation of the air and enhance evaporation is also advisable. The maintainence of a proper temperature is especially important during the early stages of the plants' growth. In an experiment in which these precautions were not observed, two unusually warm days in early spring were sufficient so to retard the development of the plants that no nitrogen was fixed. Although the plants were not noticeably injured, and in spite of the fact that numerous nodules were formed, maximum development was not attained. This dependence of nitrogen fixation on the general well-being of the plant has been noted in all of our experiments. It appears that the quantity of nitrogen fixed is determined largely by the development of the plant instead of a dependence of the latter on the available nitrogen. This view received support by the inclusion of controls to which nitrate nitrogen was added. In exposure to a variety of greenhouse conditions which resulted in different degrees of development, it was found that the nitrogen fixed by the inoculated cultures

was practically identical with the nitrogen assimilated by the nitrate controls. In all cases, the latter did not assimilate the total nitrogen available. This would indicate that under the experimental conditions employed, factors other than the available nitrogen are the limiting ones in the growth of the plant. Some of these factors are illumination, humidity, and gas exchange. Insufficient illumination slows down the growth of the plant and results in a yellowish green color, indicative of chlorosis. Artificial illumination remedies, but does not entirely correct this. Unfavorable humidity conditions and inadequate gas exchange are caused by lack of air circulation through the cotton plug of the container. On warm days water collects in drops on the walls of the container and the resultant saturated atmosphere retards transpiration. Consequently the plant is not kept properly cooled and the intake of nutrients is probably decreased. Knudson (15) observed that CO_2 uptake by strong KOH solution in cylinders open to the air was three times that of cylinders closed with cotton plugs. This decrease in rate of diffusion of CO_2 would decrease carbohydrate synthesis by the plant and the latter condition would in all likelihood be reflected in the entire metabolic activity of the plants. At present, experiments are in progress in which an effort to reduce the effect of this factor by the use of loose cotton plugs covered with a thin layer of absorbent cotton impregnated with a solution of sodium benzoate (5 per cent) and a bacteriostatic dye, *e.g.*, crystal violet. It is hoped that this method will prove efficient in preventing the entrance of microörganisms through the plug and will at the same time allow a better gas exchange. Experiments are also in progress to determine the effect of aeration on the growth of the plants.

FIXATION OF NITROGEN BY RED CLOVER UNDER STERILE CONDITIONS

The results of experiments on the fixation of nitrogen by plants grown in agar are given in table 1. A summary of 90 analyses, each analysis representing 10 to 12 plants, is presented. In order to save space, only the range of the analyses of the various samples are presented (columns 3 and 4) together with the standard deviation (column 6); this latter gives a fairly accurate idea of the "scatter" of the individual values, as in general, one-half of the values observed fell within the theoretical 0.674 times the value of the standard deviation (Probable error) measured from the mean or average. The standard deviation of the population was calculated from the usual formula

$$\text{S.D.} = \sqrt{\frac{\text{S}\,(x - \bar{x})^2}{n - 1}}$$

where x is the individual values observed, $\bar{x}$ the mean or average, and n, the number of samples considered. The average of the analyses in each series is given in column 5, together with its standard deviation calculated from

$$\sigma_{\text{mean}} = \frac{\text{S.D.}}{\sqrt{n}}$$

In column 7 is given the total nitrogen fixed per 10 (or 12 plants) with the standard deviation of this value. This latter was calculated from the formula:

$$\sigma_{diff} = \sqrt{\sigma_A^2 + \sigma_B^2}\ ^{2}$$

where σ_A = standard deviation of mean of control

σ_B = standard deviation of mean of inoculated plants.

The data in experiments I and II are divided into two groups (column 8), viz., those cultures which showed the presence of contaminating organisms at the end of the experiment and those which showed only rhizobia. It is to be noted that in neither experiment was there any indication that the presence of incidental contamination—molds and bacteria—affected the nitrogen fixed. This was true also of experiment III in which the divided data are not given, because of small numbers in each class.

The first point to be observed in the results is the actual quantity of nitrogen fixed. In experiments I and II this amounted to an average of 3.5 mgm. per 10 plants. These experiments were made in the late summer and fall. Experiment III was made from November 10 to February 22, and artificial light was used to supplement the daylight. The growth was slower, but the plants were stronger, had better color, and in general were much more healthy-appear-

[2] It should be recognized that the standard deviation calculated by this formula is only approximate and in this case is very likely a maximum value. The true formula for the standard deviation of the difference of two means is

$$\sigma_{diff} = \sqrt{\sigma_a^2 + \sigma_b^2 - 2r\,\sigma_a\,\sigma_b}$$

where r = correlation coefficient between A and B and the other symbols have the usual significance.

Lacking knowledge of the value of r it is usually assumed to be zero, i.e., the values of means are independent of each other and the formula reduces to the one given in the text. In the case under discussion, the value of r is probably positive, since experience has indicated that the larger seeds of a plant like clover, viz., one with limited food reserve, give a better initial growth, which enables the plant to fix more nitrogen. That is, the higher the mean of the control, the higher the mean of the inoculated plant. This positive value of r would lower the standard deviation of the difference, which would increase the probability of the difference being significant. In this particular series of experiments, correction of the $\sigma_{diff.}$ would not increase the certainty of the conclusions arrived at, since all of the differences noted are 10 or more times their standard deviation. However, it is well not to lose sight of the fact that the formula in the text involves the assumption that the means are independent. In the comparison of samples inoculated with different organisms, it is probable that the correlation coefficient between the mean is high and positive, since the same environmental condition would tend to affect the plants alike, independently of the organisms used. As already pointed out, the nitrogen fixed appears to be largely dependent on the growth made by the plant; therefore the assumption that r is + 1 rather than zero would probably be nearer the truth. However, in the absence of an exact determination of the value of r it is advisable to use a value which would tend to minimize the significance of the difference noted rather than to exaggerate the significance of the data. Therefore, in our experiments zero was used for the value of r; if there are any reasons to suspect that r might be negative, it is advisable to assume $r = -1$ and then use the complete formula.

ing plants. The nitrogen gained averaged 11.57 mgm. per ten plants. This was the maximum figure in any of our experiments. Experiment I was made in 32-ounce round bottles (10 plants to a bottle); experiment II, in 12-ounce bottles (6 plants to a bottle); experiment III, in round bottles and large, tall test tubes. The latter were especially satisfactory, as the increased space obviated to a certain extent the poor gas exchange. Although the absolute quantity of nitrogen fixed was not imposing, a comparison made with that

TABLE 1

Fixation of nitrogen by red clover under sterile conditions

TREATMENT	NUMBER OF SAMPLES	NITROGEN PER 10 PLANTS				NITROGEN FIXED PER 10 PLANTS	REMARKS
		Minimum	Maximum	Average	Standard deviation		
		mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Experiment I, 70 days							
Controls	8	1.8	2.8	2.23±0.12	0.33	.....	.....
Culture 200	10	4.9	7.5	5.85±0.26	0.82	3.62±0.28	Sterile
	6	4.7	6.4	5.90±0.28	0.69	3.67±0.30	Contaminated
Experiment II, 51 days*							
Controls	11	1.6	2.8	2.35±0.12	0.37	.....	Sterile
	11	1.8	3.0	2.12±0.11	0.34	.....	Contaminated
Culture 200	9	4.7	6.7	5.62±0.24	0.72	3.27±0.27	Sterile
	12	4.0	7.4	5.60±0.31	1.08	3.48±0.33	Contaminated
Experiment III,† 105 days							
Controls	10	1.8	2.8	2.25±0.09	0.28	.....	3 sterile 7 contaminated
Culture 200	13	10.7	15.9	13.82±0.42	1.51	11.57±0.43	5 sterile 3 contaminated 5 not tested

* Twelve plants in this experiment.

† Controls began to turn yellow at 45 days and were analyzed at 78 days.

originally in the seed shows that in experiments I and II the quantity of nitrogen more than doubled, whereas in experiment III it was increased fivefold. In all cases there is no question about the significance of the quantity fixed, as shown by column 6. Plate 1, figure 1, shows the influence of inoculation on clover grown in agar, and here also there is no mistaking the effect of inoculation.

That the quantity of nitrogen fixed is sufficient for the requirements of the

plants was indicated by an experiment in which, in addition to the usual uninoculated controls, 14 uninoculated controls were included to which 10 mgm. of nitrogen as KNO_3 was added to the 100 cc. of agar in each bottle. After 3 months the plants were analyzed. Both the inoculated plants and those supplied with KNO_3 were green and healthy with little difference in appearance, but the plants which were neither inoculated nor supplied with nitrate were yellow and withering. Analyses gave the following results: controls, 1.38 ± 0.04 mgm.; controls plus nitrate, 3.99 ± 0.06 mgm.; inoculated with culture 200, 3.46 ± 0.06 mgm. These results are taken to mean that the limit of nitrogen fixed in agar is a function of the growth of the plants rather than the reverse. Even though plants were plentifully supplied with nitrate nitrogen, they assimilated only about 25 per cent of that available, and their growth was no better than that of plants which obtained their nitrogen from the air.

Finally, in these experiments and in many others discussed later, no evidence was obtained that exposure of the nodule to the air is a prerequisite for assimilation of atmospheric nitrogen. The agar used was usually 0.8 per cent, just sufficient to form a firm gel; there was no indication of shrinkage from the sides of the bottle or of cracks in the body of the agar. The discrepancy of these results with those of Thornton are not easily explained. It is possible that because of the larger agar surface exposed in the containers used in our experiments, a better opportunity was available to carry on whatever gas exchange is required by the roots. Thornton does not state the diameter of the tubes used for the growth of the two alfalfa plants. From the photograph, they appear to be the 22 x 200 mm. size. A comparison of the surface exposed in these types of containers per volume of substrate is as follows:

	Total surface	*Surface per cc.*
Test tubes	400 mm.²	17.5 mm.²
12-oz. bottle	2,400 mm.²	24 mm.²
32-oz. bottle	5,700 mm.²	22.8 mm.²

From the foregoing figures it is evident that there was more surface in the large container per unit volume of substrate than in the test tubes. This would allow the equilibrium between dissolved gases and the atmosphere to adjust itself more rapidly and favor saturation of the agar with nitrogen and oxygen in the larger containers. Also, this effect is increased, because the volume of substrate per plant was higher in our experiments. Thornton used two plants per 22.5 cc. (2½ inches in test tube) or 11.25 cc. substrate per plant. In the 12-ounce bottles 16.67 cc. substrate were available per plant and in the 32-ounce bottle 25 cc. per plant. It follows that if in these larger containers there was better opportunity for gas equilibrium between the substrate and the atmosphere and there was a greater volume of substrate for each plant to use as a source of gases, this would tend to allow the plants to obtain needed gases by diffusion processes rather than by actual exposure of roots. The importance

of oxygen is not disputed in this connection, but the necessity of the plants' obtaining nitrogen through the roots makes it imperative that we do not overlook the latter gas in our interpretation.

THE EFFECT OF OTHER MICROÖRGANISMS

As noted in table 1, the presence of contaminating forms did not affect the amount of nitrogen fixed. In these experiments, however, the contaminants were accidental, and the question of whether certain organisms accompanying rhizobia in nature might aid in the fixation could not be decided on the basis

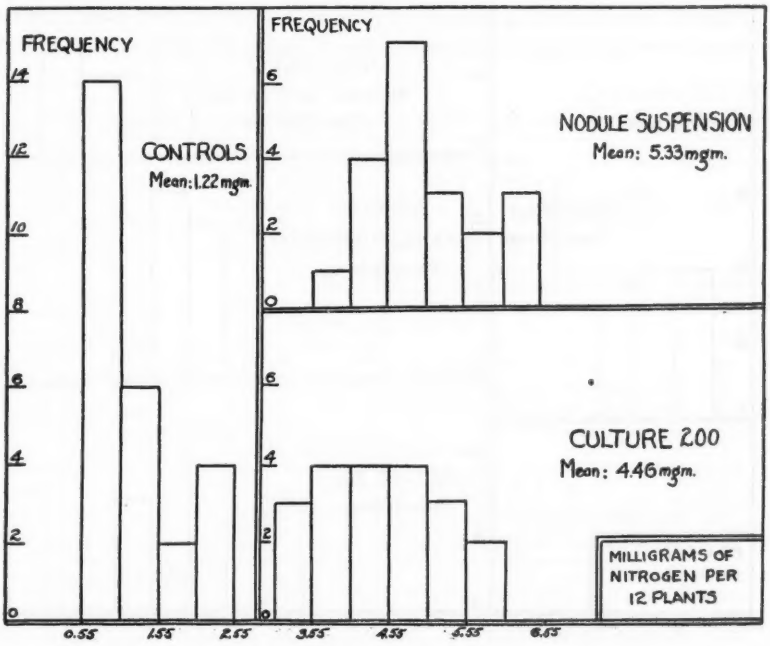


FIG. 1. FIXATION OF NITROGEN IN STERILE AGAR CULTURES (EXPERIMENT IV)

of the data given in that table. In an effort to settle this question, a number of experiments were made which would allow the presence of organisms likely to be associated with the root nodule bacteria. This was done by the comparison of nitrogen fixation by sterilized and unsterilized seeds in agar substrate and by the use of a nodule suspension in comparison with pure culture inoculum. In some cases the outsides of the nodules were sterilized by the same method as was used to sterilize the seed, whereas in others a suspension was made without this treatment. It is doubtful whether the surface sterilization actually removed all of the contaminants on the outside of the nodule, but at

least partial sterilization was effected. The results of these experiments are given in figures 1 and 2 and in table 2. In experiment IV, the data of which are given in the plates, the fixation was quite satisfactory, but in experiment V (table 2) the nitrogen fixed was only 1 to 1½ mgm. per 10 plants. Experiment V was made during the winter, and the growth of the plants was poor, hence it is probable that fixation was so repressed that differences due to treatment did not have an opportunity to manifest themselves. The data given in figures 1 and 2 show that fixation was much better in the case of the non-sterilized seeds. There was also evidence that nodule suspensions resulted in

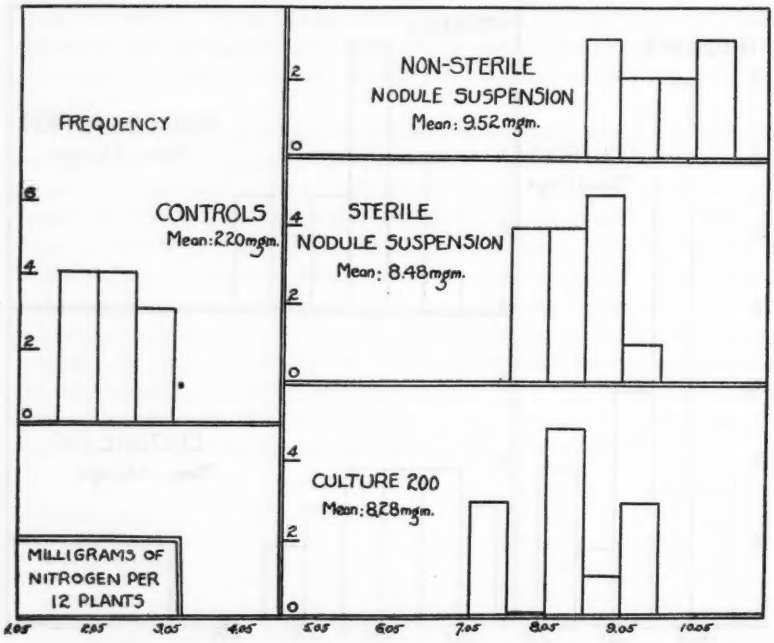


FIG. 2. FIXATION OF NITROGEN IN NON-STERILE AGAR CULTURES (EXPERIMENT IV)

larger fixation than did the pure culture. An interpretation of these data must be made with utmost caution. In view of the evidence that the quantity of nitrogen fixed is dependent on the general growth of the plant, an explanation of changes in the latter would suffice for the observations made. It is quite possible that the process of sterilization so injures the seed that it is not capable of as vigorous growth as is the unsterilized seed. Some evidence of the effect of sterilization was obtained by a comparison of total nitrogen before and after sterilization. It was found that 16.4 per cent of the nitrogen in the seed was lost in the process. The loss of this soluble nitrogen together with

other food reserves probably retards the development of the seedlings and may result in a set back that is never completely overcome. A second factor that is possibly concerned in the increased fixation noted with the unsterilized seed is the CO_2 made available by the activities of contaminating organisms. If the synthetic processes of the plants are limited by the quantities of CO_2 that diffuse through the cotton stoppers, any agent that increases the CO_2 in the culture bottle would cause an increased plant growth and, hence, nitrogen fixed. The beneficial effect of contaminating microörganisms would then be explained on the basis of CO_2 produced in their respiration.

In an effort to increase CO_2 inside the culture bottles, a few plant cultures were set up under sterile conditions with 0.1 per cent glucose added to the agar. It was expected that rhizobium or any incidental contamination would grow

TABLE 2

Comparison of fixation by red clover under sterile and non-sterile conditions (Experiment V)

TREATMENT	NUMBER OF SAMPLES	NITROGEN PER 12 PLANTS				NITROGEN FIXED PER 12 PLANTS	STERILITY*
		Minimum	Maximum	Average	Standard deviation		
		mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*per cent*
Sterilized seeds, 60 days							
Control	10	1.4	1.7	1.53±0.045	0.13	.....	86
Culture 200	10	2.3	3.1	2.67±0.073	0.22	1.14±0.086	100
Nodule suspension	10	2.7	3.6	3.09±0.086	0.26	1.56±0.097	10
Unsterilized seeds, 60 days							
Control	10	1.7	2.1	1.97±0.062	0.19	.....	0
Culture 200	12	1.9	3.4	2.73±0.141	0.49	0.76±0.154	8
Nodule suspension	9	2.9	3.8	3.25±0.097	0.29	1.28±0.115	0

* By litmus milk test (14).

on the agar and increase the CO_2 of the air by respiration of the glucose. Unfortunately the growth of the plants was not normal in the presence of the glucose; very short, stocky plants with a red pigment in their stalks were obtained. The nodules formed were fewer in number than on parallel cultures without glucose, but were very large. The fixation was 1.06 ± 0.33 mgm. for the plants grown with the glucose, and 2.08 ± 0.08 mgm. for parallel cultures without glucose.

The beneficial effect of plant passage on the efficiency of a root nodule bacteria has been observed in other work in which open sand pots were used to grow the plant. Also it has been noted that, in many cases, control pots that become accidentally contaminated from the air give a better fixation than those artificially inoculated. The view that the increased fixation with the

nodule suspensions is a question of strain efficiency is indicated by the erratic nature of the data; in some experiments no increase in fixation is obtained with nodule suspensions. (See sterile nodule suspension with non-sterile seed and

TABLE 3

The effect of strain on nitrogen fixation by the clovers and alfalfa in agar

TREATMENT	NUMBER OF SAMPLES	NITROGEN PER 10 PLANTS				NITROGEN FIXED PER 10 PLANTS
		Minimum	Maximum	Average	Standard deviation	
		mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Experiment VI, alfalfa, 90 days						
Controls	11	1.1	1.9	1.46±0.075	0.25	.....
Culture 101:						
Total	20	1.0	5.7	2.32±0.32	1.41	0.86±0.33
Series A	13	1.0	2.2	1.36±0.093	0.33	−0.10±0.12
Series B	7	3.0	5.7	4.10±0.355	0.94	2.64±0.34
Culture 100	19	2.6	6.4	4.50±0.255	1.11	3.04±0.27
Experiment VII, alfalfa, 75 days						
Controls	5	2.5	3.2	3.00±0.13	0.29	.....
Culture 101	4	3.5	6.6	5.42±0.68	1.35	2.42±0.69
Culture 100	9	4.8	7.3	6.08±0.24	0.70	3.08±0.27
Experiment VIII, sweet clover, 75 days						
Controls	5	1.9	2.8	2.24±0.17	0.38	.....
Culture 101	4	4.9	6.6	5.85±0.42	0.84	3.61±0.46
Culture 100	9	4.7	8.1	5.65±0.36	1.08	3.41±0.40
Experiment IX, red clover, controls and 202, 65 days; 200, 94 days						
Controls	10	1.4	2.0	1.67±0.076	0.24	.....
Culture 202	19	1.1	2.2	1.55±0.064	0.27	−0.12±0.10
Culture 200	17	4.9	6.9	6.08±0.146	0.58	5.41±0.17
Experiment X, red clover, 85 days						
Controls	10	1.4	2.5	1.87±0.086	0.27	.....
Culture 200	9	5.0	7.8	5.53±0.33	1.00	3.66±0.34
Culture 209	10	4.1	8.3	5.50±0.37	1.17	3.63±0.38
Culture 214	10	4.4	7.1	5.49±0.35	1.05	3.62±0.36
Nodule suspension	18	3.7	7.2	5.34±0.21	0.89	3.47±0.23

results of experiment X in table 3.) In conclusion, an increased fixation of atmospheric nitrogen took place in plants grown under non-sterile conditions, but there is evidence that this result is dependent on factors that make for a more vigorous plant growth under the conditions used to exclude microörganisms, and not on the organisms *per se*.

EFFECT OF STRAIN ON NITROGEN FIXATION IN AGAR

Observations have been frequently made regarding the importance of the strain of organism with which the plant becomes infected. Frank (4) stated that legume organisms may become parasitic. Dehérain and Demoussy (3) found that white lupines possessing numerous nodules distributed over the roots contained a higher percentage of nitrogen than plants with large nodules. Helz, Baldwin, and Fred (10) reached the conclusion that large nodules, rather than smaller ones distributed over the roots were of greater benefit to a number of legumes. The literature on the subject is reviewed in the latter paper. In view of the importance of these results from a practical as well as a theoretical standpoint, a number of experiments were made in which the fixation with different strains was compared, under conditions that would preclude any possible contamination with air-borne strains of the root nodule organism. Alfalfa and sweet clover were inoculated with culture 100, a good strain; and culture 101, a poor strain. Red clover was inoculated with culture 200, a good strain; and culture 202, a poor strain. In addition, one experiment was made in which the fixation by three good strains of the clover organism and a nodule suspension were compared. The results are given in table 3. In experiment VI with alfalfa, the fixation with culture 100 was similar to that already obtained with clover. With culture 101 two types of growth resulted, viz., the plants in 13 of the 20 bottles showed signs of typical nitrogen hunger after 2 months and resembled in all respect the controls; the other seven were practically identical with the plants inoculated with the good strain, no. 100. In the table the results of the entire 20 are given as well as a subdivison into those that did (series A) and those that did not (series B) show nitrogen hunger. There was no evidence of fixation in series A, but the fixation in series B was essentially the same as that of the plants inoculated with the good strain culture 100. In further experiments (VII and VIII) made with alfalfa and sweet clover, culture 101 proved to be as efficient as culture 100. However, because of the small number of replicates in these experiments, it is doubtful whether the variation shown in the first experiment had an opportunity to exhibit itself. The erratic behavior of culture 101 suggests that with certain cultures the efficiency to fix nitrogen is a variable characteristic and fixation or lack of fixation is largely dependent on the chance distribution of the organism of the "good" fixing type. Löhnis (18) reports a similar result with strain 205 when placed on crimson clover.

With red clover (experiment IX) the usual picture of fixation with good and poor strains was obtained. Culture 200 showed a fixation of 5.41 ± 0.17 mgm. of nitrogen per 10 plants, whereas culture 202 was not significantly different from the uninoculated controls. The types of nodules obtained on the good and bad strains was similar to those described by Allen et al. (1a) except in the case of plants inoculated with culture 101. The plants which were *benefited* by this strain had both types of nodules present. The effects of inoculation with good and poor strains are shown in plate 1, figure 2.

In experiment X are given the results obtained with several good strains of the clover organisms. In work with sand cultures these often showed different efficiency of nitrogen fixation e.g., culture 209 is most efficient and is followed in order by cultures 214 and 200. In this experiment the quantities fixed by the three strains were identical. This may be due to the fact that other factors limited the growth of the plant so that the quantity of nitrogen required was such that all these good strains could supply the needs. It is apparent that growth in agar in a closed container places such limit on the development of the plant that the method is of little value in a comparison of the relative efficiency of strains except in a gross way, as with cultures 200 and 202.

NITROGEN FIXATION BY PHAGE-SENSITIVE AND PHAGE-RESISTANT STRAINS

Gerretsen et al. (5) reported the isolation of a lytic agent or bacteriophage from nodules that was specific for the bacteria of the leguminous species from which lytic agent was isolated. This finding has been confirmed by Grijns (7, 8) and Hitchner (12). The work of Hitchner (12) and Laird (16) made evident the fact that cultures of rhizobia varied in their reaction to the homologous lytic principle. Thus with a phage isolated from red clover, certain cultures isolated from the same nodule used as a source of phage were lysed by the phage while others were not. The former were termed phage-sensitive and the latter phage-resistant. Laird continued these studies and found that the different strains of the clover organism kept as stock cultures in the laboratory had different degrees of sensitivity. By plating a given culture and picking a number of colonies he was able to determine the percentage of lysis exhibited by that culture. In this way he isolated sensitive and resistant strains from a number of stock cultures. When these cultures were placed on clover plants, he noticed a difference in the type of nodule formed, a difference similar in some respects to that observed by Allen and his associates (1a) in regard to nodule distribution on plants inoculated with good and poor strains. Apparently the reaction of a culture toward the phage used was a variable characteristic of the organism since single cell cultures of a sensitive strain would give rise to resistant strains. A similar type of variability is noticed in certain cultures of rhizobia in regard to nitrogen fixation, e.g., alfalfa culture 101.

In view of these results a number of experiments were made in which the fixation by phage-sensitive and phage-resistant strains was compared. The results of these studies are given in table 4. In experiment XI a resistant strain and a sensitive strain that were separated from a culture isolated from the nodule suspension used for the phage isolation were compared. The results showed that neither strain was able to fix nitrogen on the plant although abundant nodules were formed. Other experiments in which the phage was added at the time of inoculation confirmed this result. It was later found that the culture from which these strains were isolated was a poor type similar to

alfalfa culture 101, e.g., with some plants fixation occurred, whereas in others little or none took place. Another experiment (XII) was made in which phage-sensitive and phage-resistant strains isolated from stock cultures that

TABLE 4

Nitrogen fixation by phage-sensitive and phage-resistant strains of red clover

TREATMENT	NUMBER OF SAMPLES	NITROGEN FIXED PER 10 PLANTS				NITROGEN FIXED PER 10 PLANTS
		Minimum	Maximum	Average	Standard deviation	
		mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Experiment XI, 72 days						
Controls	5	1.4	1.9	1.70±0.084	0.19	.....
Culture 29:						
Resistant	5	1.5	1.9	1.66±0.046	0.14	−0.04±0.095
Sensitive	5	1.6	1.9	1.76±0.064	0.10	+0.06±0.106
Experiment XII, 71 days						
Controls	5	1.9	2.8	2.14±0.17	0.38	.....
Culture 205	7	5.4	9.2	7.06±0.50	1.33	4.92±0.53
R. 205–3*	6	7.1	9.5	7.38±0.58	1.41	5.24±0.60
S. 205–21†	5	4.6	7.1	6.32±0.30	0.68	4.18±0.34
Mixture R. and S	7	5.9	8.7	6.66±0.45	1.10	4.52±0.48
Culture 209	6	4.5	7.7	6.13±0.53	1.30	3.99±0.56
R. 209–12*	6	3.4	9.0	5.92±0.84	2.06	3.78±0.86
S. 209–4†	5	6.1	8.0	6.58±0.36	0.81	4.44±0.40
Mixture R. and S	7	4.5	6.8	5.57±0.33	0.86	3.43±0.37
Culture 214	6	5.6	7.5	6.43±0.29	0.72	4.29±0.34
R. 214–4*	6	5.8	9.2	6.75±0.57	1.39	4.61±0.59
S. 214–22†	5	5.6	8.2	6.60±0.46	1.03	4.46±0.49
Mixture R. and S	6	4.6	9.6	6.60±0.75	1.85	4.46±0.77
Culture 218	5	5.6	7.6	6.06±0.44	0.99	3.92±0.47
R. 215–9*	5	4.9	6.8	5.78±0.32	0.71	3.64±0.36
S. 215–18.† No nodules formed	.....	.....	.....	.....	....	.....
Mixture R. and S	5	4.7	6.4	5.20±0.32	0.71	3.06±0.36

* Resistant.
† Sensitive.

were known to be efficient nitrogen-fixing strains were used. In this experiment there were included plants inoculated with the original culture as well as mixtures of the phage-resistant and phage-sensitive strains. The reaction toward the phage of the organisms used is:

Culture 205. Good nitrogen fixer. 40 per cent sensitive
Substrain 205–3. No clearing (resistant)
Substrain 205–21. Partial clearing (partially sensitive)
Culture 209. Best nitrogen fixer. 36 per cent sensitive
Substrain 209–4. Partial clearing (partially sensitive)
Substrain 209–12. No clearing (resistant)
Culture 214. Good nitrogen fixer. 68 per cent sensitive
Substrain 214–4. No clearing (resistant)
Substrain 214–22. Complete clearing (sensitive)
Culture 215. Good nitrogen fixer. 92 per cent sensitive
Substrain 215–9. No clearing (resistant)
Substrain 215–18. Complete clearing (sensitive)

The reactions of the original culture toward the phage are taken from Laird's data[3] and were obtained by picking 25 colonies from a plating of each culture and testing these substrains against the phage; if a substrain showed complete or partial clearing during a 120-hour period, it was counted as sensitive. From some of the cultures it was possible to obtain substrains that were completely lysed by the phage whereas from others all substrains were either completely resistant or partially so.

The results of experiment XII (table 4) show that the quantity of nitrogen fixed by the sensitive and resistant strains did not differ significantly from that of the original stock culture. Culture 215–18 did not produce nodules although the organisms were obtained from the agar at the end of the experiment. This occurrence of a non-nodule producing strain has been observed on several occasions and is now under investigation in this department. In order to put all of the cultures under comparable greenhouse conditions, it was necessary to limit each set to about six bottles and thus the variability of the results was somewhat high. However, it is felt that sufficient samples were taken to establish that apparently reaction to this particular race of phage is not correlated with efficiency as nitrogen fixers. However, it is not claimed that these data completely settle this point. In all of the tests only one phage was available and it is possible that the cultures would give an entirely different reaction if other races of phage were used. Also the great variability of a given culture (even when picked from a single cell) toward the phage raises the question as to type of organism that *invades* the plant [Laird (16)]. It appears that both sensitive and resistant strains can arise from any culture so that the use of a "sensitive" or a "resistant" culture (which apparently means only predominating strains) for inoculation does not *insure* invasion of the plant by the type that is present in the largest number. This work is being continued and further reports will be made as it progresses.

SUMMARY

Nitrogen can be fixed by clover and alfalfa root-nodule bacteria in conjunction with the proper host plant in an agar substrate and under conditions

[3] Dr. Laird kindly gave us the cultures used in this work, for which we wish to express our appreciation.

that exclude the presence of any other organisms. The presence of ordinary air contaminators does not appear to affect the fixation in any way.

The quantity of nitrogen fixed in an agar substrate in bottles closed with cotton plugs varied from 2 to over 10 mgm. per 10 plants. The quantity of nitrogen fixed appears to be dependent on the general growth of the plant. Under the experimental conditions employed the plant growth is limited more by factors such as light, gas exchange, and transpiration than by a need for nitrogen, hence the latter is the dependent variable rather than the independent one.

There was evident an increase in the nitrogen fixed by plants from unsterilized seeds or inoculated with unsterilized nodule cultures. However, this increase may be due to effects tending to give increased plant growth rather than to the presence of other organisms as such.

The effect of inoculation with good and poor strains was demonstrated under conditions that excluded any chance contamination. The use of the agar culture technique for differentiating efficiencies of a number of strains is apparently limited to extremes of "good" and "poor," since factors other than need for nitrogen influence the growth of the plants to an extent that small differences in nitrogen-fixing ability are masked.

Preliminary studies on the relationship between the behavior of a culture toward a phage and its nitrogen-fixing ability indicate no correlation, but further studies of this question are necessary.

REFERENCES

(1a) Allen, O. N., and Baldwin, I. L. 1931. The Effectiveness of Rhizobia. Wis. Agr. Exp. Sta. Res. Bul. 106.

(1) Allison, F. E. 1929. Can nodule bacteria of leguminous plants fix atmospheric nitrogen in the absence of the host? *Jour. Agr. Res.* 39: 893–924.

(2) Beijerinck, M. W. 1918. The significance of the tubercle bacteria of the Papilionaceae for the host plant. *Verzamelde Geschriften* 5: 264–271, Delft, 1922.

(3) Deherain, P. P., and Demoussy, M. E. 1900. Culture des lupins 1e partie: Culture des lupins blancs. *Ann. Agron.* 26: 57–77.

(4) Frank, B. 1890. Ueber die Pilzsymbiose der Leguminosen. *Landw. Jahrb.* 19: 523–640.

(5) Gerretsen, F. C., Grijns, A., Sach, T., and Söhngen, L. 1923. Das Vorkommen eines Bacteriophagen in den Wurzelknöllchen der Leguminosen. *Centbl. Bakt.* (II) 60: 311–316.

(6) Golding, J. 1903. Experiments on peas in water culture. *Centbl. Bakt.* (II) 11: 1–7.

(7) Grijns, A. 1926. Waarnemingen omtrent den bacteriophaag bij *Bac. danicus* en *B. radicicola*. Wageningen.

(8) Grijns, A. 1927. Clover-plants in sterile cultivation do not produce a bacteriophage of *B. radicicola*. *Centbl. Bakt.* (II) 71: 248–251.

(9) Harrison, F. C., and Barlow, B. 1907. The nodule organism of the Leguminosae. *Centbl. Bakt.* (II) 19: 264–272, 426–441.

(10) Helz, G. E., Baldwin, I. L., and Fred, E. B. 1927. Strain variation and host specificity of the root nodule bacteria of the pea group. *Jour. Agr. Res.* 35: 1039–1055.

(11) HILTNER, L. 1896. Ueber die Bedeutung der Wurzelknöllchen von *Alnus glutinosa* für die Stickstoffernährung dieser Pflanze. *Landw. Vers. Sta.* 46: 153–161.
(12) HITCHNER, E. R. 1930. The isolation of a bacteriolytic principle from the root nodules of red clover. *Jour. Bact.* 19: 191–201.
(13) HOPKINS, E. W. 1929. Studies of nitrogen fixation by the root nodule bacteria of the Leguminosae. *Soil Sci.* 28: 433–447.
(14) HOPKINS, E. W., WILSON, P. W., AND FRED, E. B. 1931. A method for the growth of leguminous plants under bacteriologically controlled conditions. *Jour. Amer. Soc. Agron.* 23: 32–40.
(15) KNUDSON, L. 1916. Influence of certain carbohydrates on green plants. N. Y. (Cornell) Agr. Exp. Sta. Mem. 9.
(16) LAIRD, D. G. 1930. Bacteriophage and the root-nodule bacteria. Doctor Thesis, Univ. of Wis.
(17) LÖHNIS, M. P. 1930. Can *Bacterium radicicola* assimilate nitrogen in the absence of the host plant. *Soil Sci.* 29: 37–57.
(18) LÖHNIS, M. P. 1930. Investigations upon the ineffectiveness of root-nodules on Leguminosae. *Centbl. Bakt.* (II) 80: 342–368.
(19) NOBBE, F., AND HILTNER, L. 1899. Ueber die Wirkung der Leguminosenknöllchen in der Wasserkultur. *Landw. Vers. Sta.* 52: 455–465.
(20) THORNTON, H. G. 1930. Influence of the host plant in inducing parasitism in lucerne and clover nodule. *Roy. Soc.* (*London*) *Proc. Ser. B.* 106: 110–122.

PLATE 1

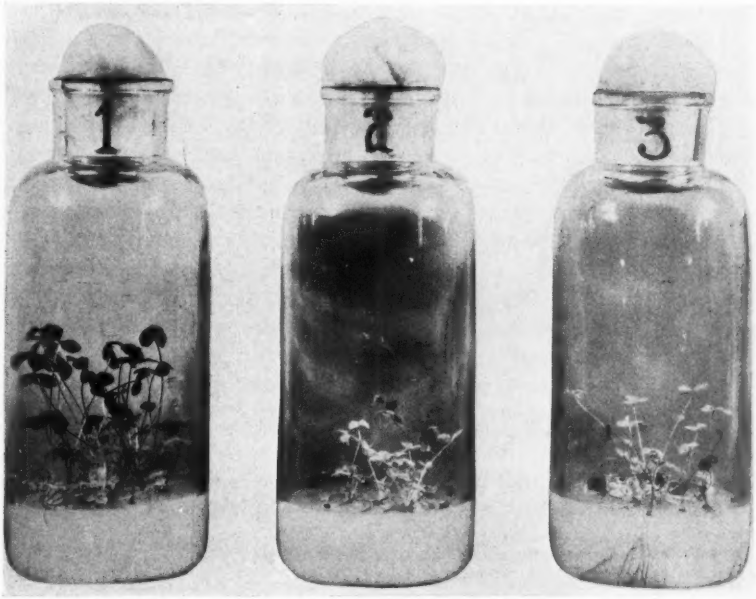
FIXATION OF NITROGEN BY CLOVER IN AGAR SUBSTRATE

FIG. 1. The influence of inoculation on clover in agar substrate.
FIG. 2. The fixation of nitrogen by effective and ineffective clover strains in agar substrate.

Control

Culture 200

FIG. 1



Clover culture 200
Effective strain

Uninoculated control

Clover culture 202
Ineffective strain

FIG. 2

CHANGES IN COMPOSITION OF SOYBEANS TOWARD MATURITY AS RELATED TO THEIR USE AS GREEN MANURE

WM. A. ALBRECHT AND W. H. ALLISON[1]

University of Missouri

Received for publication February 11, 1931

The composition of a plant is a significant factor in determining its usefulness as a green manure. Legumes make excellent green manure, ostensibly on account of their high content of nitrogen, whereas straw is detrimental on account of its low analysis with respect to this element. Soybeans are often a satisfactory green manure, for as a legume they are rich in nitrogen; yet it has been reported that the wheat crop following soybeans often gives lower yields than when not preceded by this crop. Thatcher (2) of Ohio, reports that the yield of wheat following soybeans cut for hay decreased as the date of the harvest of the soybeans was deferred. There was also a decrease in the percentage of nitrogen in the soybean roots with advancing maturity. The value of a legume for green manure depends not only on the mere presence of a certain amount of nitrogen, but also on the release of that nitrogen in a soluble form after the crop is turned under. The composition of the green manure in other respects than nitrogen, e.g. its carbon as related to nitrogen, is important. In fact, its composition as combined with that of the soil to make this a fit microbiological medium for its decomposition and nitrogen release is the final index of its value as a green manure. Since the speed and nature of the decomposition of the plant vary with maturity, according to Waksman (5), it is essential to learn more about the composition of the soybean as a possible explanation for the irregularities in its effects on succeeding crops.

The following study is an attempt to measure by chemical means the differences in organic composition of the tops and roots of the soybean plant, which accompany increasing maturity, in the belief that they may offer suggestions regarding the decomposition behavior of these plant parts in the soil.

PLAN OF STUDY

The ease of digestion by chemical reagents was taken as a rough criterion of the readiness with which microbiological digestion, or decomposition, will take

[1] Professor and formerly assistant in soils respectively, University of Missouri, Columbia, Missouri.

place within the soil. The study was based on the relative degree of solubility of the soybean plant material when the intensity of the successive chemical treatments was increased. The decomposition rate as related to chemical condition of such plant material, may be roughly divided into three divisions, as follows:

Rapidly decomposable material—that which is soluble in water.
Slowly decomposable material—that which is insoluble in water, but soluble in dilute alkali and acid.
Non-decomposable material—the residue of the aforementioned treatments, or that which is soluble in ether and strong acids.

Analytical determinations were made on the soybean materials after they had been grouped according to these treatments, or as they arranged themselves according to the ease of chemical attack. Special attention was given to the nitrogen and carbohydrates present in each group, since they play such an important part in microbial activity.

PREPARATION OF MATERIALS

The soybean plants used were collected during 1929 from fertile, well-inoculated Shelby loam soil that had been seeded with the Morse variety of soybeans on June 6. The beans were kept well cultivated throughout the summer. Beginning July 6, when the plants were about 15 inches high, a portion was harvested and at regular intervals thereafter until October. The complete plant was taken, and divided into roots and tops by cutting it about 3 inches above the ground to approximate field cutting by machine. After air-drying, these portions were ground and preserved for later study.

The summer was rather dry. The lack of rain of any significance during August caused the dropping of many leaves. During the first week in September a rainfall of 2 inches stimulated the vegetative growth. The moisture content during the season of a soil receiving similar tillage is given in figure 1.

LABORATORY METHODS

All determinations were made on the oven-dry basis, by drying the material to constant weight at 105°C. and determining the percentage of moisture. All total nitrogen determinations were made by the Kjeldahl method. The chemical treatments given the plant materials for partial digestions were those outlined by Waksman (4). The sample was first treated with ether to remove the fats and waxes which decompose very slowly in the soil and may cover other plant constituents so that the microörganisms cannot attack them. The residue from the ether extraction was treated with cold water, removing the easily soluble and readily decomposable material. This group includes the simple carbohydrates, their derivatives, various amino acids, water-soluble nitrogen compounds, and soluble minerals. The residue from the cold water extraction was then extracted with hot water, removing some of the less read-

ily decomposable materials including the starches, some pectins, certain hexoses, and various nitrogen compounds.

In order to determine the slowly decomposable group of substances, the plant residue from the hot water extraction was treated with a 5 per cent solution of sodium hydroxide at high temperature under pressure. This extraction contained alkali-soluble lignin [constituting, according to Waksman (4), about 20 per cent of the total lignin], certain hemicelluloses, and the more indifferent nitrogen compounds. The residue remaining after this treatment by the sodium hydroxide was then treated with 2 per cent sulfuric acid at

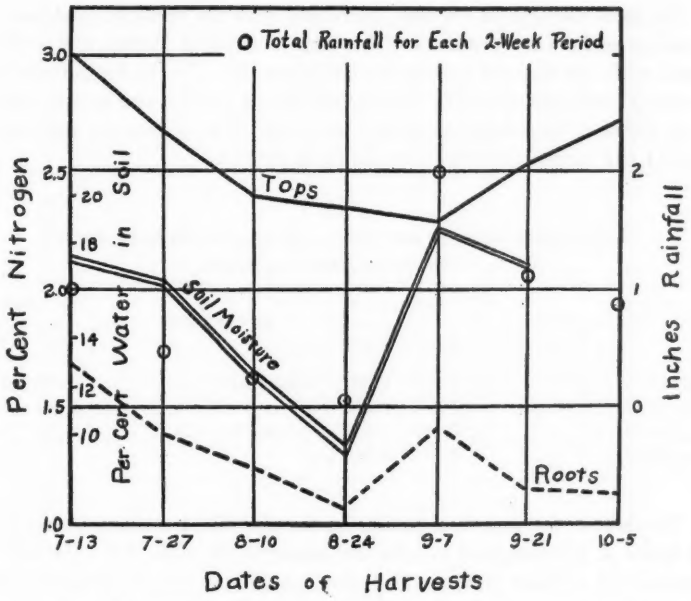


FIG. 1. NITROGEN CONTENT OF SOYBEANS DURING THE SEASON AS CORRELATED WITH SOIL MOISTURE

boiling temperature, removing another portion of hemicellulose of slow decomposition rate.

The residue from the sulfuric acid extraction was treated with ammoniacal copper sulfate (modified Schweitzer's reagent) for the determination of cellulose, whose microbiological breakdown in the soil is highly dependent on the supply of readily available nitrogen (3). The pentosan portion was determined by transforming it into furfural on heating with acid. This serves as a source of energy for soil microörganisms, and its ratio to lignin is, according to Rege (1), the basis for the rate of decomposition.

The undecomposable material, or lignin, was determined by freeing an un-

treated sample of material of its fats and waxes, and then treating it with a mixture of 18 per cent hydrochloric acid and 72 per cent sulfuric acid combined in the proportion of 1:5 respectively. This residue was classed as lignin, which decomposes very slowly, or probably not at all in the soil.

These determinations were made on soybean plant parts harvested every two weeks from July to October, as a means of determining the changes in organic composition with advancing maturity, as such might indicate variation in the amounts of decomposable and non-decomposable substance.

ANALYTICAL RESULTS

The total nitrogen in the tops fluctuated with the seasonal conditions, decreasing with the dry weather and dropping of leaves in August, and increasing again with the Autumn rains stimulating growth. In the roots there was a continual decrease until late August and then a sudden rise in nitrogen content, followed by a decrease toward maturity. These data are assembled in table 1 and correlated with the moisture in figure 1.

TABLE 1

Total nitrogen in the tops and roots of soybeans at varying stages of growth

(Per cent of water-free sample)

DATE OF HARVEST	TOTAL NITROGEN		DATE OF HARVEST	TOTAL NITROGEN	
	Tops	Roots		Tops	Roots
July 13	3.015	1.690	September 7	2.299	1.397
July 27	2.662	1.378	September 21	2.547	1.156
August 10	2.406	1.239	October 5	2.728	1.147
August 24	2.375	1.067			

The data of the analytical results for the digestive treatments, as expressed in terms of percentage of sample, are assembled in table 2 for the tops and roots of the soybean plants. The ether-soluble content, or fats and waxes, in the roots decreases gradually with maturity. In the tops there is also a decrease, with the lowest amount in late August and early September, possibly in consequence of the low rainfall of August.

For both the cold and hot water fractions there are reported four subdivisions; namely, the total substance soluble, the ash, the nitrogen, and the reducing sugars. The reducing sugar dissolved by hot water is that which was hydrolyzable by boiling in 2 per cent hydrochloric acid. According to the data for the cold water extraction, the solubility of both the tops and roots decreases with maturity. There is a corresponding decrease for both the ash and the nitrogen. There is, however, a decided increase with maturity for the cold water-soluble reducing sugar. This decrease in soluble nitrogen and the increase in soluble sugar, or carbohydrates, are significant with reference to changes in the nature of decomposition as the plant becomes more mature. It

TABLE 2

Composition of soybeans according to chemical digestion, as related to maturity of plants

(Expressed as per cent of total water-free initial sample)

FRACTION		JULY 13		JULY 27		AUGUST 10		AUGUST 24		SEPTEMBER 7		SEPTEMBER 21		OCTOBER 5	
		Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots
Ether-soluble		5.42	3.40	5.02	3.15	4.96	2.98	2.32	2.43	1.73	1.12	3.85	1.47	3.18	0.22
Cold water-soluble	Total substance	19.72	12.37	18.55	10.91	16.99	10.63	15.24	10.63	17.07	10.66	19.98	11.85	18.25	11.68
	Ash	6.18	4.34	5.20	2.41	4.82	3.68	6.07	2.91	5.33	2.96	5.54	2.90	4.59	1.79
	Nitrogen	0.92	0.54	0.90	0.31	0.74	0.35	0.91	0.32	0.83	0.32	0.64	0.32	0.52	0.31
	Reducing sugar	7.93	3.35	4.91	3.82	8.51	3.64	6.94	4.53	10.66	8.57	11.38	8.71	12.49	8.62
Hot water-soluble	Total substance	5.14	2.41	6.94	3.72	5.88	3.47	2.72	1.75	2.55	2.78	3.13	3.03	4.79	3.67
	Ash	1.09	0.39	1.70	0.79	1.33	1.11	0.80	0.53	0.68	0.64	0.81	0.47	0.76	0.45
	Nitrogen	0.24	0.14	0.26	0.13	0.26	0.06	0.16	0.13	0.14	0.10	0.15	0.13	0.18	0.15
	Reducing sugar	3.52	1.57	3.68	2.87	2.37	2.54	2.51	1.35	2.24	1.95	2.09	2.19	2.13	2.54
Alkali-soluble	Total substance	33.58	27.18	32.76	24.69	33.70	28.36	35.49	30.92	36.68	32.09	36.61	31.80	44.70	33.40
	Nitrogen	1.10	0.60	0.95	0.51	1.02	0.56	0.94	0.52	1.00	0.65	1.21	0.58	1.12	0.45
	Lignin (protein free)	2.53	1.90	2.78	1.97	5.11	2.36	2.84	1.83	2.70	1.72	2.97	2.67	2.16	2.06
	Reducing sugar	21.37	12.26	22.63	14.36	20.09	15.84	16.75	17.06	16.75	23.91	18.87	26.38	21.47	29.30
Acid-soluble	Total substance	2.47	2.94	2.64	2.99	3.13	3.01	3.19	3.52	3.59	4.41	4.43	4.37	4.67	4.63
	Reducing sugar	0.49	0.58	0.52	0.59	0.62	0.60	0.64	0.70	0.72	0.88	0.88	0.91	0.93	0.92
Cellulose		10.67	20.02	13.69	19.89	13.69	19.73	13.99	19.56	14.28	20.83	14.49	21.74	14.99	22.49
Pentosans		9.74	12.96			10.66	15.25			10.99	14.46			11.94	14.96
Lignin (ash and protein free)		11.88	9.12	12.91	18.32	13.76	17.39	15.79	17.41	18.91	17.38	22.51	17.77	23.03	22.99

designates a widening nitrogen-carbon ratio, indicating that there would be a smaller amount of soluble nitrogen liberated from the decay of material of the more mature harvest. This decrease in available nitrogen and increase in carbohydrates with maturity, especially in the roots with their already wide nitrogen-carbon ratio, may leave such excessive amounts or readily decomposable carbohydrates and such deficient amounts of available nitrogen, that the decomposition of the carbohydrates removes the soluble nitrogen from the soil and injures the succeeding crop.

The data for the hot water extract bear some resemblance to those for the total substance, the ash, and the nitrogen of the cold water treatment, but the changes with maturity are by no means so extreme. The hot water-soluble nitrogen in the roots is very low and fluctuates little through the season. The reducing sugar extracted from the roots increases but slightly, whereas that from the tops decreases slightly with maturity—the opposite of that for cold water extraction.

The fraction removed by sodium hydroxide and containing the alkali-soluble lignin, which makes up less than 20 per cent of the total lignin (5); certain hemicelluloses; and the more complex nitrogenous compounds, increases with maturity for both tops and roots. This is the reverse of the amounts soluble in cold water. The percentage of nitrogen soluble in alkali is almost constant, which may also be said of the lignin content of this fraction. The reducing sugar content of the tops remains low through the season, whereas that in the roots increases decidedly. Here again, in the roots in particular, the nitrogen remains constant while the carbohydrate increases with maturity, agreeing with the results of Waksman (5) for rye plants. This widening of the nitrogen-carbon ratio lessens the readiness of nitrogen liberation when this difficulty soluble material is decomposed in the soil.

A relatively small amount, only 2.0 to 5.0 per cent of the residue after alkali treatment, was soluble in sulfuric acid. According to the data, the total soluble substance and the reducing sugar increase with maturity in case of both tops and roots. Again in this fraction, the carbohydrate increases as the plant becomes older.

The study of the cellulose, determined by the method of Waksman (4), shows that this increases in the tops with maturity, going from over 10 per cent to 15 per cent. The roots' content of this compound remains nearly constant at the much larger figure of 20 per cent, reaching the maximum of 22.5 per cent on the last harvest date of October 5. Since the decomposition of cellulose demands the presence of certain minerals, but especially of available nitrogen, it is interesting to note the ratio of cellulose to total nitrogen in these samples at these various dates through the growth period as shown in figure 2. In the tops, this ratio was near 5:1 at the beginning, showing an increase and then a decrease with time. The roots, however, show a much wider ratio of 11:1 at the outset, becoming as wide as 19:1 in the late harvest. In comparison with the ratio of 50:1 cited by Waksman as the ratio of cellulose to available nitro-

gen facilitating cellulose decomposition, this suggests that if the supply of total nitrogen in the soybean material is all readily available it is ample for the decomposition of the cellulose. Since a good portion of the total nitrogen is combined into very stable compounds, the ease of decomposition cannot be predicted by this ratio.

It was suggested by Rege (1) that two factors control the biological destruction of cellulose, namely, energy material as pentosans and an "inhibitory factor" as lignin. The pentosans of the soybean plants were determined by the usual phloroglucide method on the harvests of 4-week intervals. This constituent increased decidedly with maturity. The lignin determination showed that this organic substance almost doubled itself, going from about 12 to more than 23 per cent in the tops, whereas in the roots it was 9 per cent at the first

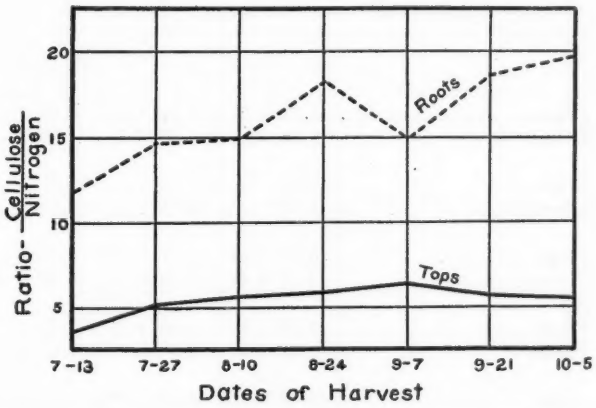


FIG. 2. CELLULOSE-NITROGEN RATIO OF SOYBEANS DURING THE SEASON

harvest, and increased to almost 18 for the rest of the dates except the last one, when it mounted to 23 per cent. Since lignin is not digested by 72 per cent sulfuric acid and is considered decomposable in the soil only very slowly, the more mature soybean plant plowed into the soil adds about one-fourth of its organic matter in a slowly decomposable form.

Rege (1) believes that cellulose decomposition depends on the pentosan-lignin ratio. This, in his opinion, should be greater than 1.0:1.0 for rapid decomposition whereas a ratio falling below this as far as 0.5:1.0 signifies slow decomposition. These ratios for the soybean plant roots at all times and for the tops on all later dates fall below the figures 1.0:1.0 and would—if Rege's deductions are significant—indicate slow decomposition of their cellulose fraction in the absence of other sources of energy.

Since the nutrient elements within the lignin are poorly available on account of its lack of decomposition, a determination of the lignin nitrogen was

made to learn how much of this element is locked up in the inert form. This remained fairly constant throughout the growth period, as shown in table 3. According to Waksman and Tenney (5), lignin contains 63 per cent carbon. Using this figure as a basis for calculation, it was found that this undecomposable or lignin carbon increases from 7.5 in the young plant to 14.5 per cent at maturity. With the content of nitrogen in the lignin remaining constant while the carbon increases, the nitrogen-carbon ratio of the lignin becomes correspondingly wider.

Because the carbon and nitrogen within the lignin are so inert, it was deemed well to subtract the percents of these two elements from their total amounts

TABLE 3

Composition of lignin of soybeans with increasing maturity

(Expressed as per cent based on lingin sample)

		JULY 13	JULY 27	AUGUST 10	AUGUST 24	SEPTEMBER 7	SEPTEMBER 21	OCTOBER 5
Ash	Tops	3.33	0.62	5.01	1.49	0.64	1.52	1.19
	Roots	6.71	3.67	4.39	4.53	4.87	8.32	10.63
Carbon*	Tops	7.48	....	8.67	....	11.91	....	14.50
	Roots	5.74	....	10.95	....	10.95	....	14.48
Nitrogen	Tops	0.49	0.61	0.41	0.45	0.44	0.49	0.48
	Roots	0.32	0.42	0.40	0.28	0.29	0.44	0.38
Protein†	Tops	3.10	3.80	2.60	2.82	2.75	3.09	2.99
	Roots	2.01	2.66	2.54	1.77	1.85	2.76	2.36
Carbon‡	Tops	39.40	40.92§	42.43	42.99§	43.54	44.59§	45.64
	Roots	40.16	41.65§	43.14	43.42§	43.71	44.15§	44.58

* Lignin × 0.63.

† Nitrogen × 6.25.

‡ Based on original water-free sample of plant material (data by L. M. Turk).

§ By interpolation from preceding and succeeding dates.

(total nitrogen, table 1, total carbon table 3) and to designate the resultant values as "decomposable carbon and nitrogen." The relationship of the carbon to the nitrogen as they are considered decomposable on this basis is expressed by the results in figure 3. These ratios are almost a duplicate of those for the total carbon to the total ntrogen in figure 4. If such conditions prevail in all plants and the assumed "decomposable carbon and nitrogen" are in accord with the facts, one might obtain an index of decomposability by simple determinations of carbon in green manures. It is significant that these ratios for the tops became widest for the early week in September, associated with the extreme of the drought, and then became narrower again with the

fall rains. In the case of the roots the reverse fluctuation occurs. Starting at a ratio of 25:1, it becomes wider then narrower and finally widens to its maximum of 39:1 in the last harvest. Since the narrower carbon-nitrogen ratio speeds decomposition (3), these soybean roots with their wide ratio would

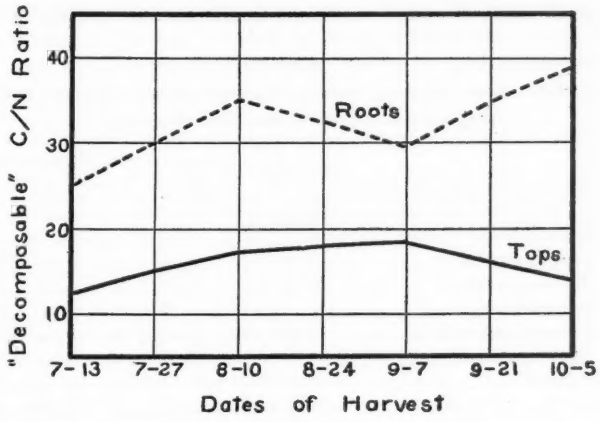


FIG. 3. RATIOS OF CARBON TO NITROGEN AS CONSIDERED "DECOMPOSABLE" FOR SOYBEANS DURING THE GROWTH SEASON

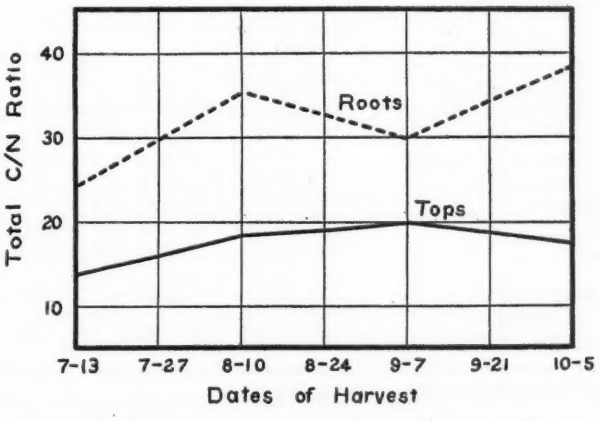


FIG. 4. RATIO OF CARBON TO NITROGEN OF SOYBEANS DURING THE GROWTH SEASON

demand an additional source of available nitrogen for rapid and complete decomposition. This nitrogen must necessarily come from the soil and, in consequence, the crop following soybeans may suffer because the decaying soybeans roots are competing with it for the soil's supply of available nitrogen.

Since microbiological digestion depends mainly on energy material, which may be found in the reducing sugars, the cellulose, and the pentosans; on the growth material, or nitrogen, which for purpose of calculation we shall consider as supplied mainly by the water-soluble and alkali-soluble nitrogen (6) in these data; and on some ash, assumed plentifully present, let us note the changes in amounts of energy material and nitrogen so supplied by the tops

TABLE 4

Readily soluble nitrogen and energy materials of soybeans as related to maturity of plants

(Expressed as per cent of total water-free sample)

	JULY 13	JULY 27	AUGUST 10	AUGUST 24	SEPTEMBER 7	SEPTEMBER 21	OCTOBER 5
Tops							
Nitrogen — Cold-water soluble	0.92	0.90	0.74	0.91	0.83	0.64	0.52
Nitrogen — Hot-water soluble	0.24	0.27	0.27	0.16	0.14	0.15	0.18
Nitrogen — Alkali-soluble	1.11	0.95	1.02	0.94	1.01	1.22	1.13
Nitrogen — Total readily soluble	2.27	2.12	2.03	2.01	1.98	2.01	1.83
Nitrogen — Balance—inert	0.74	0.54	0.38	0.35	0.32	0.54	0.90
Reducing sugars	33.33	31.76	31.61	26.85	30.39	33.24	37.04
Cellulose	10.67	13.69	13.69	13.99	14.28	14.49	14.99
Pentosans	9.74	10.20*	10.66	10.83*	10.99	11.47*	11.94
Total energy materials	53.74	55.65	55.96	51.67	55.65	59.20	63.98
Ratio $\frac{\text{Energy}}{\text{Soluble nitrogen}}$	23.6	26.2	27.5	25.6	28.1	29.4	34.8
Roots							
Nitrogen — Cold-water soluble	0.54	0.31	0.36	0.32	0.32	0.32	0.32
Nitrogen — Hot-water soluble	0.15	0.13	0.07	0.13	0.10	0.13	0.15
Nitrogen — Alkali-soluble	0.60	0.52	0.56	0.52	0.66	0.59	0.45
Nitrogen — Total readily soluble	1.29	0.96	0.99	9.97	1.08	1.04	0.92
Nitrogen — Balance—inert	0.41	0.42	0.25	0.10	0.32	0.11	0.13
Reducing sugars	17.77	21.67	22.64	23.66	35.32	38.20	41.40
Cellulose	20.02	19.89	19.73	19.56	20.83	21.74	22.49
Pentosans	12.97	13.11*	13.25	13.86*	14.47	14.71*	14.96
Total energy materials	50.76	54.65	55.62	57.08	70.62	74.65	78.85
Ratio $\frac{\text{Energy}}{\text{Soluble nitrogen}}$	39.6	56.5	55.7	58.8	65.3	71.5	85.7

* Interpolated from preceding and succeeding dates.

and roots as the plant changes with maturity. The sum of the sugars, pentosans, and cellulose is taken as energy material even though these may each have been partly included in other than its own determinations. The data assembled for the aforementioned purpose are given in table 4. The outstanding fact in these calculations is the change in the ratio of energy material to the nitrogen in the tops, but especially in the roots. In the tops this increases

from 23.6 to 34.8 during the season, whereas in the roots these figures go from 39.6 to 85.7. For the decomposition of cellulose alone, Waksman (3) cites the need of one part of available nitrogen for each 50 to 60 parts of cellulose. In the more mature soybean roots the ratio is wider than this when even partially stable nitrogen is included. Certainly this wide ratio suggests that the soybean roots supply far too great an amount of energy material in proportion to their nitrogen or growth material for ready decomposition, and suggest that such mature roots turned under would draw on the soil's supply of soluble nitrogen and endanger the succeeding crop.

SUMMARY AND CONCLUSIONS

A chemical study of the organic constituents of the tops and roots of soybeans with advancing maturity of the plants suggests that the effectiveness of this crop as a green manure to liberate nitrogen in the soil will vary widely with different stages of growth. The following facts are of interest:

The percentage of total nitrogen decreased with the age of the plant. In the roots it was only in the earliest part of the season that it reached the figure 1.70, considered by Waksman (5) as the minimum at which decomposition with nitrogen liberation occurs.

The water-soluble constituents decreased in both roots and tops as the plant became older. Less than 30 per cent of the total nitrogen was water soluble, or in the form considered by some as readily nitrifiable.

The alkali-soluble material, considered slowly decomposable, increased markedly toward plant maturity and the nitrogen content of this portion decreased, especially in the alkali-soluble lignin.

The carbonaceous material, including the reducing sugars, the cellulose, and the pentosans, all decomposable by soil microörganisms in the presence of soluble nitrogen, increased with maturity of the plant.

In consequence of the increase of carbonaceous matter and the decrease in total nitrogen, there was a widening carbon-nitrogen ratio. The study shows a far more rapidly widening ratio when the carbonaceous matter and that nitrogen which is more readily soluble are used in its calculation.

The percentage of total lignin, decomposable only slowly, increased over 100 per cent in 3 months of growth. In the tops, this increased from less than 12 to almost 24 per cent, and in the roots it mounted from about 9 to almost 23 per cent during this time. The pentosan-lignin ratio was a narrow one, which might indicate slow decomposition, especially of the soybean roots.

The depressing effect of soybeans on the crop which follows is readily possible in consequence of the large percentage of carbonaceous matter and the small percentage of readily usable nitrogen which the mature soybean crop—especially the roots—supply to the soil microörganisms. This study indicates that the percentage of more readily soluble nitrogen in the soybean crop, including both tops and roots but especially roots, decreases as the plants grow older, whereas that of the carbonaceous matter usable by microörganisms mounts so rapidly that, as a green manure, the more mature crop is a bacterial ration with excess of the carbonaceous matter and such deficiency of readily soluble nitrogen that its decomposition may jeopardize the soil's supply of

available nitrogen for other crops. There is need for fuller chemical knowledge of the changes of the organic complexes of the plant as it becomes more mature, and for a fuller knowledge of the decay of these complexes within the soil, so that chemical studies of green manures may more wisely guide their use for maximum effective nitrogen liberation in the soil.

REFERENCES

(1) REGE, R. D. 1927 Biochemical decomposition of cellulose materials with special reference to the action of fungi. Ann. Appl. Biol. 14: 1–44.

(2) THATCHER, L. E. 1925 The soybean of Ohio. Ohio Agr. Exp. Sta. Bul. 384.

(3) WAKSMAN, S. A. 1927 Principles of Soil Microbiology, p. 702, 727. Williams & Wilkins Co., Baltimore.

(4) WAKSMAN, S. A., AND TENNEY, F. G. 1927 Methods of quantitative analysis of plant materials. *Soil Sci.* 24: 275–283.

(5) WAKSMAN, S. A., AND TENNEY, F. G. 1927 Influence of age of plant upon rapidity and nature of decomposition. *Soil Sci.* 24: 317–333.

(6) WHITING, A. L. 1926 Some important factors controlling the rate of nitrification of organic material. *Jour. Amer. Soc. Agron.* 18: 854–876.

THE EFFECTS OF VEGETATION AND CLIMATE UPON SOIL PROFILES IN NORTHERN AND NORTHWESTERN WYOMING

JAMES THORP

U. S. Department of Agriculture, Bureau of Chemistry and Soils

Received for publication October 14, 1930

During the summer seasons of 1927, 1928, and 1929 soil surveys were made of the agricultural lands of the Big Horn Basin and Sheridan County in Northern and Northwestern Wyoming. Practically all of the mature soils of the Big Horn Basin are fundamentally the same from a scientific standpoint, but as one ascends the surrounding foothills and mountains, striking differences in soils and in vegetation may readily be observed.[1]

Many botanists and zoologists have recognized and described the variations of plant and animal life which are encountered as one ascends the slopes of high mountains to progressively cooler and moister regions, and many scientists have recognized that soils vary, in their fundamental characteristics, in a similar way. Glinka (4) and other eminent European soil scientists have recognized the existence of soil zones paralleling climatic zones in the mountains and have written more or less voluminously on the subject. In the United States but little detailed study has been made of this phenomenon although a number of scientists have recognized its existence. Because of the limited time at the disposal of the writer the studies are rather limited in scope, but sufficient data were gathered to be used in forming a fairly comprehensive idea of the processes which have been, and are at present, contributing to the nature of the mature soils of this region.

The territory under discussion includes: first, the terraced lands of the Big Horn Basin from Worland and Tensleep north to Lovell and northwestward to Powell, Elk Basin, and Cody; second, the western slopes of the Big Horn Mountains from Hyattville to Shell, which border Big Horn Basin on the east; third, Yellowstone Park, which is separated from the Big Horn Basin by the Absaroka Mountains (a range of the Rocky Mountain system); and fourth, the eastern slope of the Big Horn Mountains and the edge of the great plains which surround the cities of Buffalo and Sheridan.

[1] While working on the soil surveys the writer spent many week-ends in taking trips into the mountains to gather field notes and soil samples to show these differences. He was accompanied and assisted on some of these trips by Mr. E. G. Fitzpatrick of the Bureau of Chemistry and Soils and on two or three occasions by Mr. T. J. Dunnewald of the Wyoming Agricultural Experiment Station.

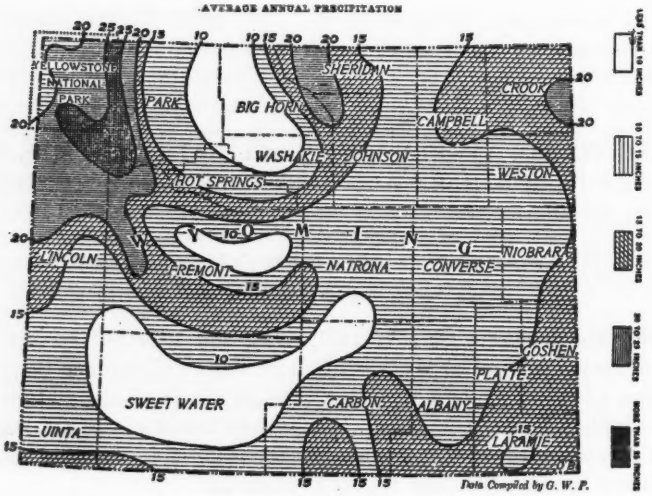

AVERAGE ANNUAL PRECIPITATION
YELLOWSTONE NATIONAL PARK
PARK
BIG HORN
SHERIDAN
CROOK
CAMPBELL
WASHAKIE
JOHNSON
WESTON
HOT SPRINGS
WYOMING
LINCOLN
FREMONT
NATRONA
CONVERSE
NIOBRARA
GOSHEN
PLATTE
SWEET WATER
CARBON
ALBANY
UINTA
LARAMIE
Data Compiled by G. W. P.

FIG. 1

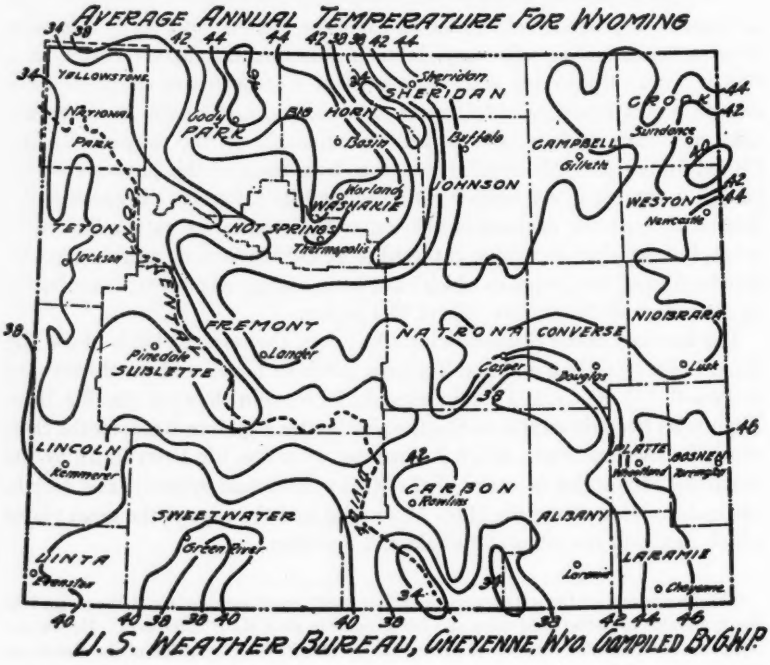

AVERAGE ANNUAL TEMPERATURE FOR WYOMING
YELLOWSTONE NATIONAL PARK
Cody
PARK
BIG HORN
Basin
Sheridan
SHERIDAN
Buffalo
CROOK
Sundance
CAMPBELL
Gillette
JOHNSON
Worland
WASHAKIE
WESTON
Newcastle
HOT SPRINGS
Thermopolis
TETON
Jackson
FREMONT
Lander
NATRONA
CONVERSE
NIOBRARA
Pinedale
SUBLETTE
Casper
Douglas
Lusk
LINCOLN
Kemmerer
PLATTE
GOSHEN
Torrington
CARBON
Rawlins
SWEETWATER
Green River
ALBANY
UINTA
Evanston
Laramie
Cheyenne
U.S. WEATHER BUREAU, CHEYENNE, WYO. COMPILED BY G.W.P.

FIG. 2

CLIMATIC VARIATIONS

The variations in precipitation in the part of Wyoming which we are considering may be illustrated most briefly by the accompanying Weather Bureau map of the State (fig. 1) with a few statistics from the same source (9). A study of Weather Bureau figures (9) shows an average precipitation of approximately 6 inches for the larger part of Big Horn Basin, which places it in the

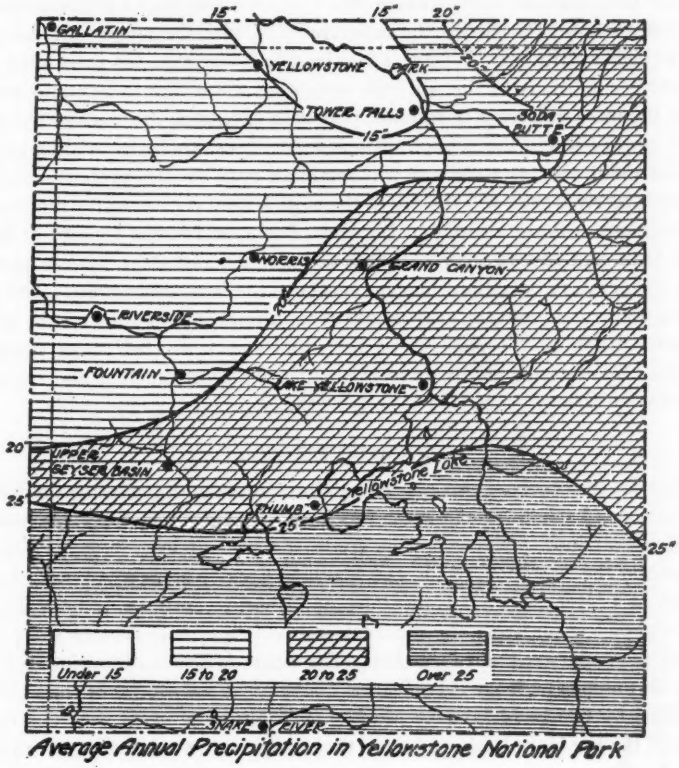


FIG. 3

class of true deserts. Surrounding Big Horn Basin are concentric bands of territory which have progressively greater amounts of precipitation until the higher peaks of the Absarokas on the west, and of the Big Horns on the east are reached. The maximum annual precipitation of which there is record in the Big Horns is 24.74 inches at Dome Lake (9). Since this station is centrally located it probably closely approximates the average rainfall for the major part of the mountains. Estimates of as high as 40 inches per annum have

been made by various scientists but it is doubtful whether there is that amount of rainfall in any considerable area in the Big Horns. A precipitation map of Yellowstone Park (3) is presented (fig. 3) to supplement the Wyoming map. From this it may be seen that the average annual rainfall considerably exceeds 25 inches in the Absarokas. From the mountain tops the total rainfall decreases westward and eastward respectively with the corresponding decreases in altitude. A study of the isothermal lines (9) showing average annual temperatures for Wyoming (fig. 2) shows that they are distributed in positions roughly paralleling the moisture belts, with the cooler portions lying at the higher altitudes. With this in mind one is warranted in presuming that moisture conditions in the soil will vary even more than one would expect from the mere difference in rainfall; that is to say, since the warmer temperatures prevail where the precipitation is least, the evaporation will be greater at this point also, and the soil will retain an even smaller proportion of the water it receives than will the soil in the more humid regions of the mountains. The regions of lower altitude in Big Horn Basin, and in the vicinity of Sheridan, have cold winters, cool autumns and springs, and short warm summers. The temperature variations in the mountains are less pronounced. The winters are very cold and the snow banks remain until late in June on the higher slopes. A few of the peaks have perpetual snows on their more sheltered slopes. Snowstorms are likely to occur any month of the year and there are usually fairly heavy snowfalls as early as the latter part of September.

SOILS AND VEGETATION

It is not the object of this paper to go into great detail regarding the minute differences of structure and color which were observed in the great mass of profiles examined. These may be studied in part at least in the soil survey reports of the Shoshone, Basin, and Sheridan County areas which will be published at a later date. It is our purpose rather, to describe, in brief, typical soil samples taken from the different soil belts and endeavor to show their relations to climate and vegetation. The writer is also endeavoring to correlate his findings with the classification of the great soil groups of the world as outlined by Glinka (4) and by Marbut (5). We shall begin with the desert soils of the Big Horn Basin and trace the changes eastward and westward from this locality.

Mature soils in the Big Horn Basin are found lying chiefly on a series of gravel terraces which were laid down in Quarternary times (7). These terraces range from 20 to several hundred feet above the levels of the chief river courses of the Basin and constitute a large portion of the higher lands. There are also fairly large areas of rolling uplands which are underlaid by sandstones and shales. Mature soils are often found on the sandstones but the shales are so resistant to weathering that soils derived from them are usually very thin and immature.

The vegetation on the desert is so sparse that it is easy to observe the general

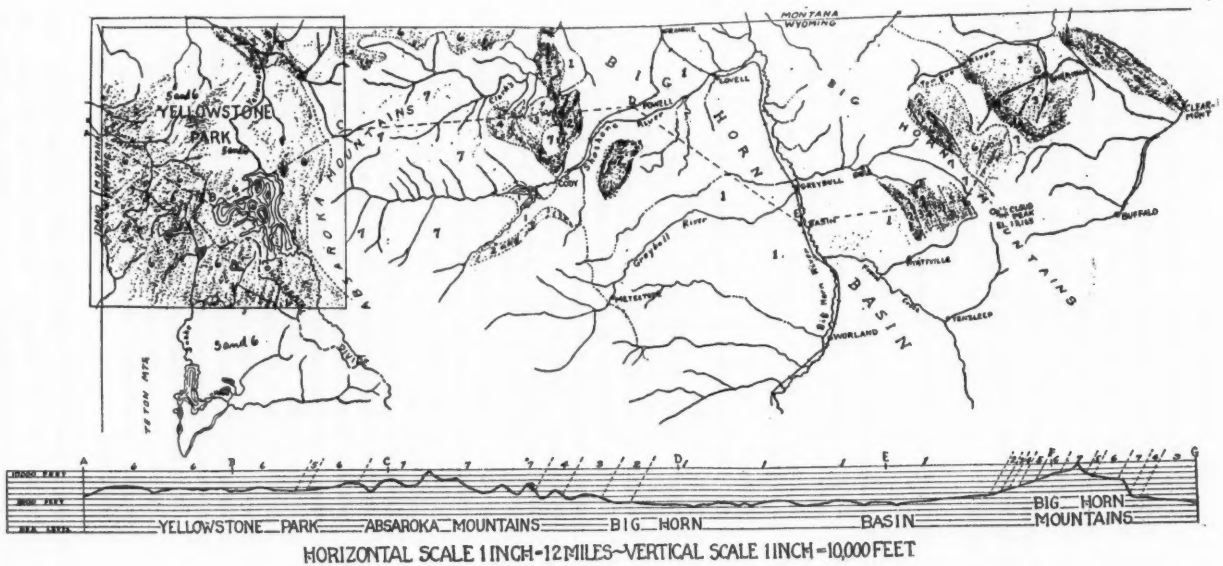


FIG. 4. MAP AND CROSS SECTION OF NORTHWESTERN AND NORTH CENTRAL WYOMING SHOWING SOIL BELTS AND THEIR RELATION TO ALTITUDE

color effect produced by the soils from any eminence. Standing in such a place on a day when the soils are thoroughly dry one notes that the general color of the landscape is a pale grayish brown, except where exposed rocks of different colors vary the conditions. Where the parent rocks of the mature soils are red this gray-brown color will be found only in the top inch or two of the soil profile, but where the color of the parent material is of a more sober hue, it extends to a greater depth. A composite profile description in outline form will serve to illustrate the characteristics of the desert soils of northwestern Wyoming. These soils have been designated as group 1 and the other groups will be taken up in order.

Group 1.—Pale gray-brown desert soils (8)

Depth of Horizon	*Description*
0– 1 inch A_1	Pale gray-brown "crust and mulch." Crust one-fourth to three-fourths inch thick, quite hard when dry, and filled with small ovate vesicles one-sixteenth inch in diameter. Mulch of very fine, loose angular soil aggregates when texture is heavy, and single grain structure when soil is light textured.
1– 6 inches A_2	Light grayish to yellowish brown slightly laminated soil of medium texture.
6– 9 inches B_1	Compact, cloddy, yellowish brown soil of slightly heavier texture than above horizon. Most compact in profile.
9–18 inches –40 inches B_2	This is the horizon of lime accumulation and as indicated varies greatly in thickness. It occurs as vertical streamers of light gray to nearly white crypto-crystalline lime deposit alternating with yellowish brown, limy soil. The proportion of lime decreases rapidly in the lower part of this horizon and none is visible below it. Very commonly there is a deposit of white or pinkish crystalline or crypto-crystalline gypsum interspersed with the upper layers of the parent material beneath the lime horizon. Soluble salts are often found below the gypsum.
18–40 inches down C	The parent material may be rounded gravels of various igneous, metamorphic, or sedimentary rocks, or it may be red, yellowish brown, or gray sandstone. Where the sandstones are red their color persists in the horizons which underlie the crust and mulch. Pebbles and larger stones throughout the profile are almost invariably coated with lime, either entirely or on their under sides. This lime is usually more or less indurated. On the high older terraces lime is rapidly accumulating along the weathering cracks in the stones. This is especially true of the basic igneous gravels. In the C horizon the gravels and sandstones retain most of their original characteristics, showing only a slight amount of weathering.

When the composite profile described in the foregoing is exposed in a road cut or along a stream channel, several things of interest are noticeable. In the first place it forms a series of fairly distinct columns which are noticeably

resistant to weathering. These columns are most noticeable in the lower A and B horizons. When thoroughly dried they are very hard and difficult to break up. The lime accumulation is soft and friable when moist but it often becomes slightly indurated when dry. Another striking characteristic of the profile is that a test with dilute hydrochloric acid gives a very strong effervescence from the surface downward. This is undoubtedly due to the fact that rainfall is insufficient to carry the lime down to the lower from the upper horizons as fast as carbonation takes place in the soil.

In numerous small flats or slight depressions there are usually small areas of "slick spots." In these places the soil has characteristics similar to the normal types but in a much more pronounced form. The columns are more clearly cut and harder to destroy; the lime accumulation is usually dense and there is a much greater accumulation of gypsum in the lower horizons. As soon as these lands are irrigated they become "puddled" and a heavy accumulation of soluble salts appears at the surface unless ditch or tile drains are provided.

The shales of this part of the country, as mentioned in the foregoing, so interfere with weathering as to prevent the maturing of the soils derived from them. Some samples taken in these shale soils showed that although the total depth of the solum was only 6 or 8 inches, the same series of horizons could be found as in the soils described above. This type of profile might be said to be dwarfed rather than immature in the stricter sense of the word.

The vegetative cover on the mature desert soils is usually quite light. It consists chiefly of two species of plants; namely, sagebrush (*Artemisia tridentata*) and salt sage or Winter fat (*Eurotia lanata*). The following table gives some of the less abundant plants and the nature of the soils with which they are associated.

PLANTS		SOILS
Common name	Botanical name	
Rabbit brush	*Chrysothamnus* (several)	Very sandy soils
Shadscale	*Atriplex confertifolia*	"Slick spots"
Greasewood	*Sarcobatus vermiculatus*	Salty spots (poorly drained)
Prickly pear	*Opuntia*	Medium and light textured soils
Grama grass	*Bouteloua oligostachya*	Normal types
Needle grass	*Stipa*	Normal types
Fleabane	*Erigeron*	Normal types
Pentstemon	*Pentstemen nitidus* Dougl.	Residual uplands
Paint brush	*Castilleja angustifolia*	
	Castilleja buffumi Nels.	Normal types

There are many others.

These plants are not all confined to the soil types with which they are listed but are more abundant on those types and rarer on the others. However the shadscale and greasewood seldom spread beyond the slick and salty soils to which they are respectively adapted.

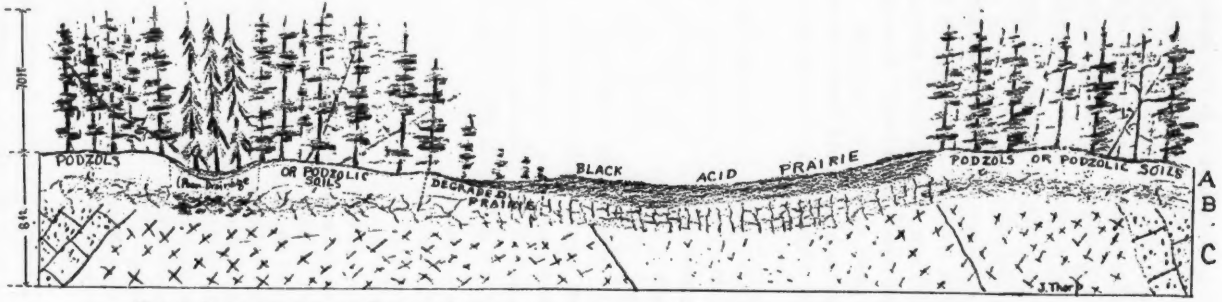


FIG. 5. RELATIONSHIPS OF SOILS TO FORESTS AND PRAIRIES IN YELLOWSTONE AND IN BIG HORN MOUNTAINS

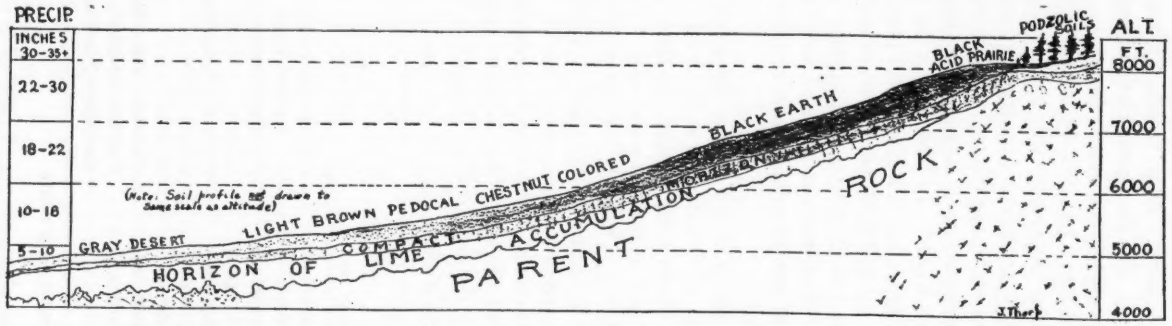


FIG. 6. GRADATION OF SOIL PROFILE FROM DESERT TO HUMID MOUNTAIN TOP—WEST SLOPE OF BIG HORNS

Near the edges of the desert, where the rainfall is slightly greater, there is an increase in the amount of vegetative cover. The proportions of grasses and flowers increase and the salt sage gradually disappears. The sagebrush, however, persists and is very abundant in the moister regions of the mountain slopes.

Group 2.—Light brown soils

If we travel into the mountains eastward or westward from Big Horn Basin and are careful to follow smooth slopes where the soil has been undisturbed for a long period of time we find that the color of the A horizon of the soil changes very rapidly as progressively moister regions are reached. The first noticeable color change is to a light brown instead of gray. Tests with acid show little or no effervescence in the A horizon but Soiltex tests indicate that the pH is well over 7. The slightly compact or heavy horizon which is always found in this region just above the lime accumulation shows effervescence with HCl as do the horizons beneath. The lower horizons differ but little from those in the desert. Areas of this soil may be found near Hart Mountain, near the northwestern edge of the Basin, and on the lower slopes of the Big Horns near Hyattville and Shell. The vegetation on this type of soil has a much greater percentage of grasses and but very little salt sage. Sagebrush, however, is usually abundant.

Group 3.—Chestnut brown soils

Still higher on the mountain sides the A horizon becomes thicker, dark brown, and the pH value is about 7. The heavy layer in this type is thicker also and is cloddy and columnar. It contains a film of brown colloidal material spread over the surfaces of the clods. The depth to the lime accumulation is still greater than in the soils of group 2. Grasses and sagebrush constitute the principal vegetation.

Group 4.—Black earths or chernosem

In this group the A horizon is from 12 to 15 inches thick, is laminated in the upper part and structureless in the lower part, and is neutral to slightly acid in reaction. The heavy layer is thicker than that in group 3. It is somewhat granular in structure and the granules are coated with brown colloidal material from the A horizon. The horizon of lime accumulation is thinner than in group 3. This soil supports a vegetation similar to group 3 except that it is more abundant.

Group 5.—Acid prairie soils

On the higher mountain tops where the vegetation is grass instead of timber and where the rainfall is over 20 inches the soil is a black or brown acid prairie. There is a laminated black soil about 1 foot deep underlaid by a yellowish brown, compact, granular horizon in which the soil aggregates are coated with brown organic colloids from the above horizon. At a depth of about 2½ or

3 feet is the rotten rock material which constitutes the C horizon. The vegetation is chiefly grasses of various species with some Artemisia and a great profusion of wild flowers including lupine, Castilleja, Delphinium, Dodecatheon, and Myosotis. This soil in general strongly resembles the acid prairie soils of Iowa and Illinois.

Group 6.—Podzolic soils

The sixth group of soils exists under the same rainfall conditions as the soils of group 5, the only different factor in their environment being that of vegetation. This group of soils is always found with a heavy forest covering constituted chiefly of Lodgepole pine (*Pinus murrayana*) with some alpine fir (*Abies subalpina*) at high altitudes. Englemann spruce (*Picea englemannii*) is quite common in some parts of the mountains, particularly in moist areas. In many places the timber cover is so heavy that there is little undergrowth. However, where the trees are less plentiful there are some small shrubs and many bright flowers, one of the showiest of which is *Castilleja lauta*.

The soils of this group were developed under an annual rainfall of from 20 to 35 inches. Since they are at a high altitude where the average annual temperature is low, the "soil climate" is moister than one would expect from the absolute amount of the precipitation.

The sixth group of soils probably belongs with Glinka's podzols or podzolic soils, as a brief description of one of them will show. This sample was taken in the Big Horn Mountains in a thick grove of lodgepole pine and spruce.

DEPTH	HORIZON	DESCRIPTION
inches		
0–½	A_0	Raw humus of rotted pine needles, roots, wood, etc.
½–1½	A_1	Dark brown structureless loam
1½–6	A_2	Ashy gray structureless loam
6–12	B_1	Pale yellowish, heavy gravelly loam streaked with dark-colored material from above
12–26	B_2	Reddish yellow and yellow mottled gravelly loam, less heavy than B_1
26–40	C_1	Yellow mottled with reddish yellow rotten granite fragments

The entire profile is strongly acid in reaction, as tested with Soiltex. In several places it was observed that the forest was gradually encroaching on the adjacent prairie. In these places the black topsoil of the prairie was deep just outside the edge of the timber, slightly shallower where there were scattered young conifers, noticeably thin where the forest was becoming more dense, and entirely lacking where the original stand of heavy timber was reached. This transition takes place within a distance of from 50 to 100 yards. In places where the edge of the forest has evidently been stationary for a long period of time the transition from the podzolic soil to the black prairie takes place within a distance of 8 or 10 feet.

In endeavoring to correlate the findings of this investigation with the work of Marbut and of the Russian soil scientists, the writer recognizes the possibility of making errors in judgment. The reader should bear this in mind when considering the material presented in the following:

Proposed correlation of the soil groups of northern Wyoming with the great soil groups in the United States and Europe

WYOMING SOILS (J. THORP)	SOILS OF U. S. (C. F. MARBUT)	SOILS OF EUROPE (K. GLINKA)
Group 1	Gray desert	Gray desert
Group 2	Brown pedocal	Brown (light chestnut)
Group 3	Dark brown pedocal	Chestnut colored
Group 4	Black earth	Chernosem
Group 5	Prairie	Not listed
Group 6	Podzolic	Podzolic

The mountainous character of much of the country and the differences in vegetation have caused minor differences between some of the Wyoming soil groups and their corresponding broad groups elsewhere in the world. Groups 1 and 2 and perhaps 3 more closely resemble their corresponding groups elsewhere than do groups 4 and 5. The podzolic soils of the Big Horns and of Yellowstone Park were not separated into gray-brown forest soils and podzols because no satisfactory method was found for locating division lines.

The major banding of soil groups in northern Wyoming around the Big Horn Basin has been described. A similar condition prevails east of the Big Horns, but group 1 is missing. Group 5 is found on the mountain tops but groups 2, 3 and 4 occupy the foothills and plains to the east. Group 4 is limited in extent to a narrow strip of land close to the foot of the mountains. Group 3 extends in tongues to a few miles east of Sheridan, and group 2 extends many miles eastward to the Black Hills region.

Undoubtedly these belts are found on the rolling plains instead of on the mountain slopes because the rainfall decreases less rapidly with the altitude on the east side of the mountains than it does on the west side. Sheridan has an annual precipitation of 14.43 inches as opposed to 5.96 inches at Basin, which occupies a similar physiographic position in the Big Horn Basin (9). Although there are no weather stations at the foot of the mountains south and west of Sheridan it is the opinion of the Weather Bureau men at Sheridan and of the writer, based on observation, that the rainfall increases rapidly between Sheridan and the foot of the mountains. Corresponding to this probable increase in rainfall there is a decided darkening of the A horizon in the soil. Farmers consulted testified to a greater rainfall in those parts where the mature soils are dark colored.

Another banding of soils which corresponds strikingly with the climatic zones is to be found in northern Yellowstone Park. An examination of the precipitation map of Yellowstone Park (fig. 3) reveals an area of low annual

fall around the lower reaches of the Yellowstone River and its tributaries. Because of the lack of time no soil samples were taken here but careful observations were made. Near the north edge of the park along the Yellowstone River there is a strip of group 2. Farther up the river and its tributary, the Lamar, members of groups 3 and 4 were successively observed. Elsewhere in the park, where the precipitation is heavier, groups 5 and 6 were observed and sampled.

SOIL REACTION

A number of pH tests of several of the samples were made[2] and these were supplemented by field tests made with Soiltex. In table 1 are given the approximate average pH values for the three principal horizons of each group of soils.

TABLE 1

pH values of northern Wyoming soils

SOIL GROUP	HORIZON A	HORZION B	HORIZON C
1	8.55	9.22	8.25
2	8.5*	9.3*	8.0*
3	6.5–7.0*	9.0*	8.0*
4	6.0–7.0*	9.0*	8.0*
5	6.2	6.5	7.0
6	4.9	5.7	6.1

* Values determined by Soiltex tests; others determined by hydrogen electrode or quinhydrone methods.

CONCLUSIONS

Detailed observations seem to warrant the following conclusions regarding the effects of vegetation and climate upon soil profiles in northern and northwestern Wyoming:

The presence or absence of lime in the soil, as determinable by ordinary field observations, depends upon the humidity of the soil as determined by the rainfall combined with the average annual temperature. Where the rainfall is light, lime forms in the soil more rapidly than it can be leached out by percolating waters, and it accumulates in a horizon which lies at the depth of average moisture penetration. As the rainfall increases, the depth to this horizon of lime accumulation increases until under a rainfall of approximately 20 inches it disappears altogether insofar as can be determined by simple tests with acid.

Gypsum and salt accumulations disappear sooner than the lime under the conditions mentioned in the foregoing.

The thickness of the heavy subsoil or upper B horizon increases with the increase in rainfall, other things being equal. This is the horizon of maximum illuviation.

The color of the soil is determined largely by the proportion of grasses in the vegetation, e.g., the more grass, the darker the soil. Of course the amount of grass is largely dependent upon the rainfall in turn.

[2] Tests made by Ernest Bailey of the Bureau of Chemistry and Soils.

Under like conditions of rainfall and parent material a forest vegetation causes the formation of an altogether different soil from that formed under a prairie vegetation.

Topsoils in this region have a pH value of 6.5 or more when the precipitation is less than 20 inches, and less than 7.0 when it is 20 inches or more. The pH values are lower in forested soils than in prairie soils under the same rainfall conditions. In the pedocals the pH is highnest in the horizon of maximum lime accumulation, whereas in the acid prairie and forest soil it is highest in the C horizon.

SUMMARY

This article deals with the effects of vegetation and climate upon soil profiles in northern and northwestern Wyoming. Differences in climate are due to the great variation in elevation, whereas differences in vegetation are closely allied with those of climate. The soils have been grouped into six great classes based upon important profile differences. Soils are pale gray-brown on the desert and, with the exception of group 6, become progressively darker with the increase in altitude and rainfall. The sixth group, associated with heavy conifer forests, is light colored. The first four groups belong to the pedocals (soils having horizons of lime accumulation). They are separated from one another chiefly on the basis of the darkness of the color of the A horizons. Groups 5 and 6 are both in humid zones but differ greatly in profile characteristics. This difference is due to the great difference in vegetative cover. Group 5 has a heavy sod of grasses and flowers with no trees, whereas group 6 has a heavy growth of conifers. Parent materials are frequently the same under both groups.

APPENDIX

The appended table gives certain essential relationships between soils and precipitation and vegetation in this region.

SOIL GROUP	TOPSOIL COLOR	PRECIPITATION	VEGETATION*
		inches	
1	Pale gray-brown	5–10	Salt sage, sagebrush, rabbit brush, needle grass, grama grass, fleabane, pentstemon, prickly pear, paint brush, shadscale
2	Light brown	10–15	Sagebrush, salt sage, grama and other grasses, lupine, larkspur, paintbrush, pentstemon, Mariposa lily, wild buckwheat, some juniper, loco, and Gaillardia
3	Chestnut brown	15–18	Same as above with no salt sage and with more sagebrush and a heavier sod
4	Nearly black	18–20	More grasses and sagebrush than above
5	Black or brown	20–40	Little sagebrush; heavy sod of grasses, lupine, pentstemon, paintbrush, Gaillardia, harebell, forget-me-not, shooting star, etc.
6	Ashy gray	20–40	Lodgepole pine, Douglas fir, Englemann spruce, ground juniper, lupine, paint brush, harebell, gentian (moist spots), and others

* Common names,— see below for botanical names.

*List of plants identified**

COMMON NAMES	BOTANICAL NAMES
Fleabane	*Erigeron*
Forget-me-not	*Myosotis alpestris*
Gaillardia	*Gaillardia aristata*
Gentian	*Gentiana serrata and others*
Grama grass	*Bouteloua oligostachya*
Greasewood	*Sarcobatus vermiculatus*
Ground juniper	*Juniperus communis sibirica*
Harebell	*Campanula rotundifoiia*
Indian paint brush	*Castillija angustifolia, C. buffumi* Nels. (on soils 1 and 2); *C. pallescens, C. linariaefolia* (on soils 3 and 4); *C. lutea* Heller (soil 5); *C. lauta* Nels., and *C. confusa* Greene (soil 6). There are several others
Juniper	*Juniperus scopulorum*
Larkspur	*Delphinium geyeri* Greene and others
Lupine	*Lupinus* (a large number of species not differentiated by the writer)
Mariposa lily	*Calochorius Nuttallii* and *C. Gunnisonii*
Needle grass	*Stipa* (specific name not determined)
Pentstemon	*Pentstemon nitidus* Dougl. (soil 1); *P. cyaneus* Pennell; and *P. Caryi* Pennell (soils 2, 3, and 4); *P. procerus* Dougl., *P. procerus pulvereus* Pennell, *P. pseudoprocerus* Rydb., *P. fruticosus* (Pursh), (on soils 3, 4 and 5). There are several others in this region
Prickly pear	*Opuntia*
Rabbit brush	Chiefly *Chrysothamnus dumosa*
Sagebrush	Chiefly *artemisia tridentata* with a number of less common species
Salt sage or winter fat	*Eurotia lanata*
Shadscale	*Atriplex confertifolia*
Shooting star	*Dodecatheon pauciflorum*
Wild buckwheat	*Erigonium* (species?)

* Dr. F. W. Pennell, Curator of Plants, Philadelphia Academy of Natural Sciences and Dr. A. Nelson of the University of Wyoming furnished most of the plant identifications.

REFERENCES

(1) CLEMENTS, E. G. 1920 Flowers of Mountain and Plain. H. W. Wilson, New York.
(2) COULTER, J. M., AND NELSON, A. 1909 New Manual of Rocky Mountain Botany. American Book Co., New York.
(3) FLETCHER, E. H. 1927 Climatic features of Yellowstone National Park. Sci. Mo. 25: 329–336.
(4) GLINKA, K. D. 1914 The Great Soil Groups of the World and Their Development. Trans. by C. F. Marbut, 1927; Edwards Bros., Ann Arbor, Michigan.
(5) MARBUT, C. F. 1928 Soils, Their Genisis, Classification and Development. U. S. Dept. Agr. Graduate School Lecture Course (mimeographed).
(6) PENNELL, F. W. 1920 Scrophulariaeceae of the Central Rocky Mountain States. *Contributions from the United States Herbarium*, vol. 20, part 9.
(7) DARTON, N. H. 1906 Geology of the Big Horn Mountains, p. 90. U. S. Geological Survey.

(8) THORP, J., ET AL., Soil survey of Basin Area, Wyoming. U. S. Dept. Agr. Bur. Chem. and Soils in cooperation with Wyo. Agr. Exp. Sta. (Report soon to be published).

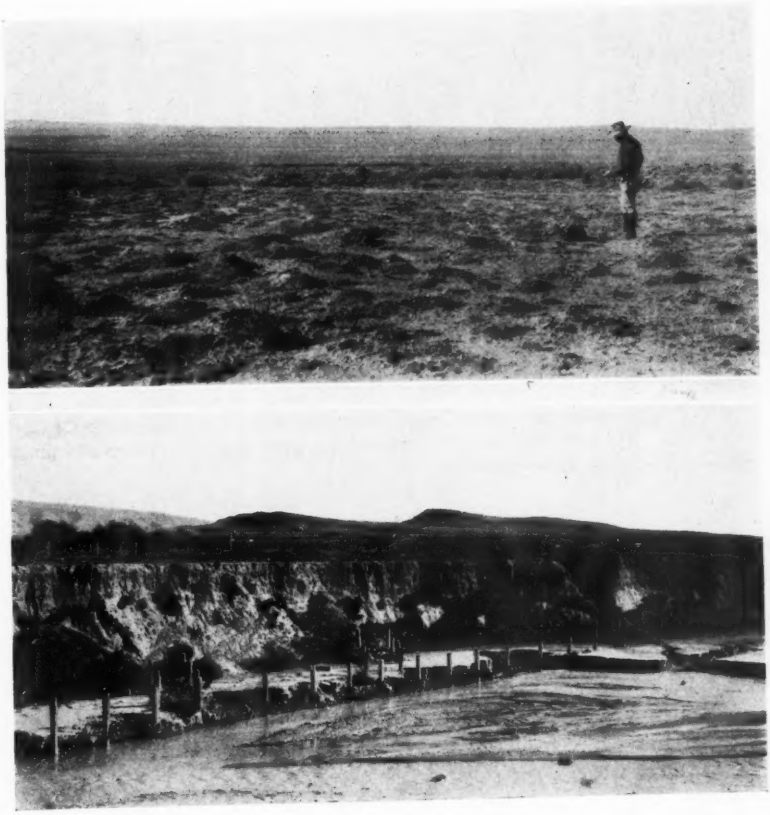
(9) Wyoming Agricultural Statistics, No. 5, 1927; U. S. Dept. Agr. Bur. Agr. and Econ., and Wyo. State Dept. Agr. Issued by Wyoming State Department of Agriculture, Cheyenne, Wyo.

PLATE 1

The Gray-brown Desert Soils of Big Horn Basin

Fig. 1. Typical vegetation on gray-brown desert soils of Big Horn Basin. In foreground are clumps of salt sage (*Eurotia lanata*) and some grama grass (*Bouteloua oligostacha*). In the middle ground is a colony of sagebrush (*Artemisia tridentata*). Taken near Basin, Wyo.

Fig. 2. Showing how the gray-brown desert soils of Big Horn Basin stand in vertical columns where exposed by erosion. Taken near Lovell, Wyo.



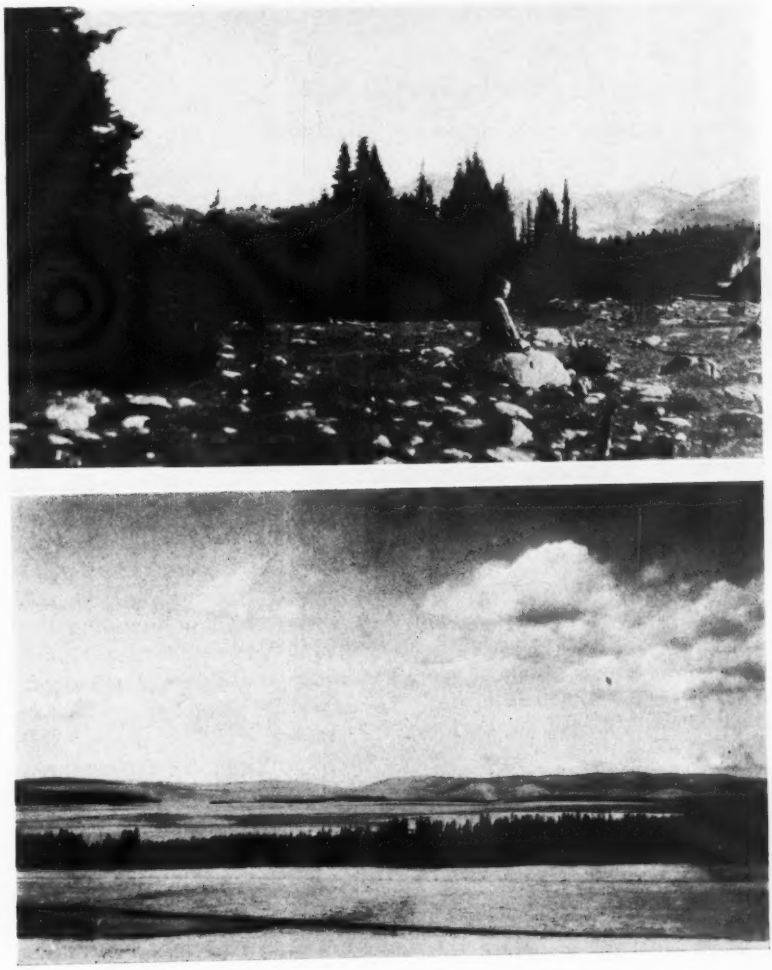
FIGS. 1 AND 2

PLATE 2

ACID PRAIRIE AND PODZOLIC SOILS IN THE BIG HORN MOUNTAINS

FIG. 1. Showing open grassy lands and alpine fir thickets at 9,000 feet elevation in Big Horn Mountains. Soils under timber are podzolic; those with grass are brown acid prairie

FIG. 2. Open prairie with strips of lodgepole pine forest at 8,500 feet elevation, Big Horn Mountains. The road in the foreground exposes the black surface soil of the acid prairie. Soils in the forested areas are podzolic.



FIGS. 1 AND 2

SOIL PROFILE STUDIES: III. THE PROCESS OF PODZOLIZATION

J. S. JOFFE

New Jersey Agricultural Experiment Station[1]

Received for publication February 10, 1931

In connection with the soils profile studies conducted at this station, the process of podzolization as evident in the soils of New Jersey has been investigated. In view of the general interest in the theories of the process, it was deemed advisable to present first a discussion of the subject.

HISTORICAL

Long before the true nature of podzols was established the bleached layer just a little below the surface of the soils was observed and noted. Almost a century ago Sprengel (45) described what we know now as podzol soils.

Scandinavian and German foresters and geologists also noted and described podzols. In the excellent work of Müller (33) mention is made of the views held by some Danish geologists, especially those expressed by Selmer, that the ash-gray to white horizon in some of the forest soils in Scandinavia is not formed in situ, but it has been brought in by the winds or laid down by water. They considered the bleached horizon as an independent geologic stratum. Müller and later Ramann (39) refuted the idea about the white layer being an independent geologic formation, but they did not explain either the origin or the process responsible for the "white" sand formation. Not until the Dokuchaev school of soil science revealed the genetic relationship of the soil horizons in the profile was it possible to elucidate the mode of formation of the bleached layer in the forest soils of the temperature region and the North. As a matter of fact Dokuchaev (7, 8, 9) began his soil studies on the podzols of the Smolensk region in Russia. But it was Sibirtzev (41) who separated these soils into a special type.

Ever since the classical researches of Dokuchaev the podzol soils have been studied in great detail and a wealth of information has accumulated on the process of podzolization. Close to 200 papers are cited bibliographically by Glinka (18) just on the soils in the podzol zone within the boundaries of the U. S. S. R. In recent years the literature on podzols has been augmented by a series of papers in German and English, especially since 1914 when the work of Glinka (19) became available to the German reading workers and later to the English readers through the translation by Marbut (19).

For our purpose it will suffice to mention the work of just a few Russian

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of soil chemistry and microbiology.

investigators as well as the more important work of others whose investigations have a direct bearing on the subject under discussion.

THEORIES ON THE PROCESS OF PODZOLIZATION

In all the studies on podzol soils the process of podzolization has been linked with the soil organic acids and organic matter in general. Ramann (39), Dokuchaev (9), Sibirtzev (41), Glinka (18) in his early work, and a number of other investigators stressed the rôle of the organic acids in the process of podzolization. They were under the influence of the German workers Mulder (31, 32) and Detmer (5), who subdivided the soil humus into neutral and slowly moving ulmin and humin and into slightly soluble humic acids and easily soluble crenic and apocrenic acids.

Dobrovol'skii (6) summarized the work on podzols up to the year 1900. He systematized the data in tabular form and on the basis of these and his own work he concluded the following:

> The upper horizons are high in total SiO_2 because the other constituents are leached out. In general podzols are rich in Fe and poor in Ca. The P content of the A horizon is lower than that of the B. When wet the bleached horizon is a sticky, smeary mass, which upon drying hardens and when crushed becomes powdery, silty like, especially in the loams.

In his work with the podzols Dobrovol'skii attempted to differentiate the organic matter in the respective horizons. An $(NH_4)_2CO_3$ extract from the A_1 horizon gave a dark brown solution; from the A_2 bleached horizon, a red-yellow solution. When neutralized with acid, humic acid settled out from A_1 but not from A_2. The filtrate from A_1 resembled in color the extract from A_2. Both the filtrate from A_1 and the extract from A_2 upon addition of $CuSO_4$ gave a precipitate of a dirty green color (crenic and apocrenic acids). In the bleached A_2 layer there is little apocrenic acid; it is mostly the less oxidized stage—the crenic acid. There is no humic acid in this horizon, which is therefore white or ash-gray.

Bogoslovskii (4) traced the southern limits of the podzol process in Western Europe. He points out that the podzolization process might be extended to the yellow and red soils of the Mediterranian where it is not so intense as north of that zone.

Williams (55), whose views on the processes of soil formation are at some variance with the orthodox Dokuchaev school of soil science, applied the modern knowledge of base exchange and other replacement reactions to the scheme on the differential rôle of the various organic acids—especially crenic and apocrenic—in the process of podzolization.

Because of a definite similarity between the views of Williams and Dobrovol'skii, cited in the foregoing, they are presented at this point.

The process as pictured by Williams[2] is as follows: The crenic acid formed

[2] Williams rarely presents experimental data to prove his points. His treatises are primarily of a scholastic, speculative, and philosophical nature. In some respects they are extremely interesting.

in the decomposit on process of the forest litter reacts first of all with the carbonates of calcium, liberating CO_2 and forming calcium crenate, which is soluble. Not until all the lime has disappeared does the crenic acid react with the other elements of the parent material. Iron and manganese are attacked next, forming creantes of these elements, which are also soluble and are therefore carried downward. The loss of iron and manganese causes the whitish or gray color. After leaching out of the sesquioxides, which according to Williams (55, p. 116) are

> . . . . always present in the parent material in a very fine state of division, the kaolin or the hydrate of alumino-silicic acid ($H_2Al_2Si_2O_8 \cdot nH_2O$) is disintegrated by the crenic acid. Under the influence of this acid, free sols of silicic acid are separated out, whereas the aluminum forms the crenate. Other metals of the same group—iron, chromium, and manganese—also form crenates.
>
> The aluminum crenate is leached downward. Some of the silica sol moves downward in colloidal state, some turns into gel, which loses water and in an amorphous state fills the interspaces in the parent material imparting to it the white color and a structureless condition.
>
> Such is the complexity of phenomena which results in the formation of the podzolized horizon in the upper layer of the parent material.

The products of the podzol process of soil formation are classified by Williams into two groups:

> 1. Mineral salt of all the elements of plant nutrients formed in the decomposition of the forest litter and:
> 2. The salts of the organic acids rich in nitrogen—the crenates of Ca, Fe, Mn, and Al.
>
> In the podzol horizon neither bacteria—because of the acid medium due to the crenic acid—nor fungi—because of the crenic acid which is a waste product of the fungi—may develop. It thus becomes a dead horizon where only mineral reactions will take place.

Kossovich (26) in discussing the processes of soil formation sums up the podzol process as follows:

> It takes place under conditions of sufficient or excess of moisture. The organic acids together with the carbonic, nitric, and perhaps sulfuric acid act on the mineral constituents and dissolve the bases. Finely divided organic substances in colloidal state are also active. During periods of saturation ferrous salts might be produced which leach out. Primarily, however, aerobic conditions exist and the iron probably moves as the sol protected by the organic colloids. Silica is usually left behind. As a result of the leaching of bases the horizon of eluviation is acid. The horizon of illuviation becomes enriched with electrolytes which are responsible for the precipitation of the iron and aluminum, which serve as cementing material for the ortstein formation or incrustations. Some of the fine clay particles are also caught in their downward movement in the horizon of incrustations or ortstein which is identified as the B horizon. As a result, this horizon becomes compact even if the parent material is not of clay origin.
>
> The processes described are responsible for the formation of a grayish-white horizon just below the humus accumulative horizon. It is poor in bases, iron, aluminum, and colloidal substances in general, and acid in reaction. In soils poor in organic matter or in sandy soil, this layer is practically free from organic matter, poor in bacteria, and rich in fungi mycelium. This process prevails in the northern part of the temperate zone. At the northern and southern limits of this zone the so-called intrazonal gradations of podzols are found. Within the

zone one finds regions of true podzols, strong podzolization, medium podzolization, and light podzolization.

Among the more important investigations on the process of podzolization are those of Zakharov (56). He analyzes the process of podzolization with reference to the moisture régime as influenced by the macro and micro-relief of the region. He outlines the development of the various types of podzols from a slightly podzolized soil to a peat podzol and finally to a peat-gley. His conclusions are similar to those of Tumin, whose work is discussed presently and who presented diagramatically the idea of relief influence (fig. 4).

Tumin (50) separates the podzol zone into five belts. In the center of the zone there is a true podzol belt. To the north and south of it there are the two belts of podzolized soils, and north and south of these there are the two belts of weakly or slightly podzolized soils. The differences in the analogous belts—

TABLE 1

Variations in the degree of podzolization due to the mechanical composition of parent material

PORTION OF THE ZONE	BELTS	SOILS ON LOAMS	SOILS ON SANDY LOAMS	SOILS ON CLAY LOAMS	LOWER BLEACHED HORIZON (BELOW B)
Northwestern portion	5	Weakly podzolized	Podzolized	Podzols	Present
	4		Podzols	Podzolized	
Central portion	3	Podzols	Podzolized	Weakly podzolized	Is disappearing
Southeastern portion	2	Podzolized	Weakly podzolized	Weakly podzolized	Absent
	1	Weakly podzolized	Weakly podzolized	Weakly podzolized	

north and south of the central true podzol belt—consist of the following: in the northern belts we find more organic matter and a higher reducing activity (due to more frequent saturation) than in the southern belts.[3] There is another morphological distinction between the analogous northern and southern belts. In the soils of the northern belts there is a bleached whitish horizon below B; none such is found in the southern belts.

In figures 1 and 2, reproduced from Tumin (50, p. 324), a podzolized and a true podzol soil with a bleached horizon (Ba_2) below B are represented.

Tumin points out that the fall in the intensity of podzolization both in the northern and southern belts is conditioned by the two principal climatic factors: rainfall and temperature.

The fall in degree of podzolization in the south-eastern direction takes place under conditions of lower rainfall and higher temperature; in the north-western direction—under conditions of higher rainfall, lower temperature, and decreased aeration.

[3] In reality the belts do not run north and south, but northwest and southeast.

According to Tumin (50)

> The description outlined on the distribution of podzols, podzolized, and weakly podzolized soils is true for loams on a level plain topography. Otherwise the morphology of each belt in the podzol zone is closely related to the relief, mechanical and chemical composition of the parent material.

In table 1, Tumin presents

> . . . . a crude scheme of the distribution of the podzols, podzolized, and weakly podzolized soils in connection with the variations in the mechanical composition of the parent material.
>
> Changes in the degree of podzolization in connection with fluctuations in relief take place in the direction from a higher elevation to depressions. The degree of podzolization will change in the same manner as it does in a given parent material as we advance to the northwest. In the southeastern zone (first belt) the podzolization on loams, sandy loams, and sands increases in the direction of the depressions, i.e. in this belt true podzols are to be encountered in the depressions only.
>
> In the central portion of the zone (third belt) podzolization weakens on loams in depressions and increases on the sandy loams and sands. It is perfectly clear that with the transition into depressions the deoxidation process and accumulation of organic matter (peat formation) increase in the soil horizons. With the approach toward the depressions the depth of some of the horizons increases. A new sub-horizon A_1', darker in color than A_1 appears; it replaces A_1 in the depressions and wherever peat is formed it is gradually covered by the peat layer A_0 which finally replaces it. [*See* fig. 3.]

A graphic illustration of the aforesaid is given in figure 4, reproduced from Tumin (50, p. 328). It shows how A_0 gradually replaces A_1 with the change in microrelief.

"The presence of carbonates in the parent material tends to depress podzolization." Under such conditions an intrazonal morphological type known as "rendzina" is formed.

> The amount of humus in the soils of the podzol type varies as follows: at the extreme northwest and southwest there is an increase in the humus content; from these extremes toward the central portion of the zone the humus content decreases.

In another paper Tumin (49) differentiates the processes of podzolization and leaching of bases. The latter is true also for other soil processes. Podzolization is intimately related with the light colored humus substances—crenic acid—and the dark colored—humic acid. It is the predomination of the crenic acid over the humic acid in the A_2 horizon of the podzol profile that determines the podzolization effects.

Tumin (49) disagrees with Sibirtzev (41, p. 257), who, in his pioneer work on podzols, pointed out the parallelism between podzolization and the separation of SiO_2 in the bleached horizon. To Tumin the accumulation of the light colored humus is the characteristic feature of podzolization.

Glinka (18) has shown experimentally—by igniting soil from the bleached horizon—the presence of the light colored humus substances: upon ignition the material darkens, which indicates carbonization of organic matter.

Neustruev (35) in discussing the relationship of the organic acids to the process of podzolization justly remarks: "No one has proved the presence of crenic acid and in general its existence and properties are thus far hypothetical."

In an attempt to establish the conditions of iron and aluminum precipitation in podzol soils, Aarnio (/) conducted a series of experiments on the rôle of humus in these reactions. He obtained ammonia humus extracts from two peats, dialyzed them for 5 weeks and then mixed definite quantities of the extracts with variable quantities of iron and aluminum sols. From the data on the iron and aluminum coagulates, ratios were obtained for the amount of humus (by weight) necessary to coagulate one unit (by weight) of Fe_2O_3 or Al_2O_3.

One humus extract gave a ratio ranging from 1 Fe_2O_3:2.79 humus to 1 Fe_2O_3:0.90 humus; the second humus extract gave a ratio 1 Fe_2O_3:2.46 humus to 1 Fe_2O_3:0.82 humus. For aluminum the ratios with the respective humus extracts were: 1 Al_2O_3:30.12 humus to 1 Al_2O_3:1.20 humus and 1 Al_2O_3:26.62 humus to 1 Al_2O_3:5.32 humus. This would indicate that colloidal iron under the influence of humus moves deeper into the soil profile than aluminum.

Aarnio found that colloidal SiO_2 and the anions SO_4 and PO_4 are also instrumental in precipitating the iron sols.

In a second paper dealing with the same subject Aarnio (2) presents more data. He shows how the ratios vary with the type of humus source. He points out that in soils with a high humus content there is a tendency for a low $Fe(OH)_3$ and a high $Al(OH)_3$ content.

Smirnov (44) attempted to demonstrate experimentally the process of podzolization. Tubes, 5 cm. in diameter, were filled with soil material from a podzol sandy soil. First the material from the C horizon was placed in the tubes followed by A_2 and A_1. The B horizon was left out in order not to hinder percolation. The percolates consisted of: distilled water, distilled water saturated with CO_2, and a weak ammonia (1:100) solution. From time to time 50–60-cc. portions were titrated. The H_2O percolates were yellowish brown and acid in reaction, requiring for neutralization 0.25 to 0.5 cc. of 0.01 *N* NaOH. The CO_2 percolates were colorless and alkaline for the first 3 days after which they became acid. The ammonia extract was acid, dark brown, and continuous leaching with ammonia produced under the A_2 material a ring resembling ortstein formation.

A thorough discussion of the process of podzolization is presented by Glinka. His many investigations and observations are presented in the two compilations of his life work (16, 18). His views may be summarized as follows:

Fundamentally the process of podzolization is nothing more than the carrying away of the mobile sols of humus deprived of its calcium from the surface horizons. These sols also serve as a protective agent for the downward movement of the fine mineral suspensions. All of these mobile substances are deposited in the B horizon.

The white coating which gives the characteristic appearance to the bleached horizon consists of finely powdered quartz sand which remains on the surface of clay lumps from which the finest clay particles and the hydrates of iron oxide have been washed away. Glinka (18, p. 336) states:

> It has been proposed that the white coating is a result of the splitting off of the silicic acid in the process of silicate decomposition by the humic acids. If that were the case one would expect an appreciable quantity of silica soluble in alkali and alkali carbonates. Experiments, however, show that in podzols there is no more soluble silica than if the alkali would react with finely powdered quartz.
>
> Besides that, if the silica in the podzolized horizon represents the residue from the decomposition of the silicates, one would expect to find in the B horizon considerable quantities of aluminum hydroxide, which is not borne out by the experiments of Gemmerling. The small quantities of free hydrates of aluminum found by Gemmerling in the ortstein might come from the ash constituents of the plants.

Gedroiz (13) interprets the process of podzolization in the light of base exchange reactions. Whenever conditions are favorable for the replacement of the cations in the soil complex (mineral or organic) capable of base exchange with hydrogen-ions, podzolization takes place. Such conditions prevail in the climatic regions of moderate rainfall where the percolating waters exclude the accumulation of soluble salts.

TABLE 2

Water extract analyses in per cent of weight of soil

SOIL	DRY RESIDUE		SiO_2	$Al_2O_3 + Fe_2O_3$	CaO	HUMIS (BY TITRATION)
	Ordinary drying	Igniting				
Original chernozem.....	0.0575	0.0195	0.0095	0	0.0107	0.0360
Chernozem saturated with H.....	0.1140	0.0504	0.0430	0.0055	0	0.0605

Pure water upon dissociation gives at 22°C., 10^{-7} gm. of hydrogen ions per liter. In the presence of carbonic acid, the amount of hydrogen ions appreciably increases since the dissociation constant of this acid is 3×10^{-7}. A still greater increase in the concentration of hydrogen ions takes place in the presence of organic acids, which are the products of organic matter decomposition. The processes of nitrification and sulfur oxidation introduce into the soil solution the highly ionized nitric and sulfuric acids. Thus the concentration of hydrogen ions in the soil solution may reach at some time a magnitude of considerable moment.

The energy of replacement of hydrogen is higher than that of Ca, Mg, K, and Na. It means that the replacing power of the H ion when compared with an equimolecular or ionic quantum of Ca, Mg, K, Na, or a combination of these in solution, is greatest. On the other hand, the total concentration of the other cations—Ca, Mg, K, Na—either individually or in combination, might reach a quantum whereby the total energy of replacement of them becomes high enough to suppress the activity of the H ions.

Gedroiz (13, p. 66) points out that

> . . . . water circulating in the soil when saturated with CO_2 under pressure of one atmosphere will contain 10^{-5} gm. of H ions per liter; under the same conditions the solubility of $CaCO_3$ will bring into solution about 5×10^{-1} gm. of Ca per liter, i.e. its concentration will be 50,000 times higher than that of the H ions. It is perfectly clear that in the presence of calcium and magnesium carbonates in the soil, or any other more soluble salts, the processes which take place in the parent material and in the soils will not tend to produce an unsaturated complex.
>
> Thus the formation of an unsaturated soil complex and hence of a soil unsaturated with bases is possible only when almost all of the easily and difficultly soluble salts have been leached out and carried down to a depth from which the capillary rise of moisture cannot bring them to the surface horizons.

The replacement of the bases with hydrogen and the formation of an unsaturated complex (organic and mineral) are not the only result of the action of water on the soil. To quote Gedroiz (13, p. 68):

> Water exerts on the soil alumino-silicates (and humates) not only the influence of base replacement; it also partly disintegrates them at the same time, converting them into more simple compounds and partly decomposing them into the simple oxides of iron, aluminum, and silica. The action of water on the aluminum silicates and humates unsaturated with bases is a good deal more effective than on the silicates which have not reached that stage yet.
>
> To give some idea of how water is more active on soils unsaturated with bases, analyses are presented in table 2. A 100-gm. portion of natural chernozem saturated with Ca and Mg, and a 100-gm. portion of the same chernozem from which the bases had been removed and replaced with hydrogen were each mixed with 500 cc. of water. Both mixtures were kept for 3 days and the water extract was analyzed.
>
> Thus the soil loses not only the bases but also the colloidally dispersed humus and the complex mineral compounds which decompose into silicic acid and hydrates of the oxides of aluminum and iron. In this way the processes of degradation and podzolization lead, on the one hand, to the formation in the soil of insoluble compounds unsaturated with bases and, on the other hand, to their decomposition.

According to Gedroiz (13, p. 69) the process of podzolization consists of two stages:

> *First stage.* The hydrogen ion of the water replaces the absorbed bases in the absorbing complex which is unprotected by the presence of minute quantities of simple salts against the entry of these ions.
>
> *Second stage.* The portion of the complex unsaturated with bases begins to be energetically disintegrated by the water. The colloidally dispersed humates are carried downward and the aluminum silicate portion of the unsaturated complex is decomposed into silica and the oxides of iron and aluminum.

Thus the views of Gedroiz on the process of podzolization differ somewhat from those of Glinka inasmuch as the latter does not admit that in this process the aluminum and iron silicates decompose completely leaving behind most of the silica, while the iron and aluminum move downward. In the scheme of Gedroiz the decomposition process is one of the essential features. Besides

that, Gedroiz postulates the formation of aluminum silicates anew in the B horizon through the mutual coagulation of the positive Al and negative SiO_2 sols.

Ortstein and concretion formation

There is a general agreement that in the process of podzolization a translocation of mineral and organic substances—crystalline and primarily colloidal—takes place in the soil profile.

Eluviation and its complement illuviation find expression in the morphological features and chemical composition of the soil profile. The horizon of eluviation—A—becomes impoverished of bases, sesquioxides, colloidal mineral and humus particles, and its complex capable of base exchange becomes unsaturated. It has no definite structure. The horizon of illuviation becomes enriched with the substances from the A horizon and attains a definite morphological appearance, chemical composition, and physical make-up. Its general features are common to all groups of podzols: it is darker in color, more compact, has structure, contains more clay and electrolytes, and is higher in base exchange capacity than the A_2 horizon.

In certain important details, however, the B horizon differs in various podzols. One of the variable elements is the ortstein formation which is identified with the B horizon in the podzol zone. Not all podzols, however, possess ortstein or even concretions, and these new formations are not therefore to be looked upon as inherent to the process of podzolization.

Ortstein formation has been known for a long time. Müller (33) distinguished three fundamental groups: (*a*) ortstein due to washing in of fine particles, (*b*) orstein formed by absorption of humus and iron, (*c*) ortstein of a concretional origin. In the last group Müller places also a type of bog iron formation which should not be classed with the ortstein because ortstein is a formation of the downward movement of substances and bog iron is a product of the rising waters.

Ramann (40) identifies podzols with pan formation. According to him (40, p. 69):

> The pan is a layer of the soil cemented together by humus and since the podzols are preponderately sandy soils, this is a humus sandstone. Soft, easily friable pans may be termed "earthy pans" (Orterde).

Ramann (39, p. 167) differentiates three forms of ortstein: (*a*) "branderde" which forms a mass rich in organic matter but not cemented together, (*b*) ortstein hard as a rock, dark brown to black, with an average content of organic matter; it is encountered in the northern part of Germany, (*c*) a dark brown ortstein, very hard, containing a small amount of organic matter; it is usually very thick and is overlain by a softer and lighter layer.

Warrington (54) points out that humic acids dissolve out iron, which moves downward and precipitates on sand, forming iron pan.

An extensive study of podzols and ortstein formation has been made by Tamm (48). He considers ortstein as unweathered material cemented with colloids, primarily iron (limonite), and humus. Ortsteins rich in humus are soft, whereas those rich in iron are hard.

Chemical analyses of ortstein and orterde are presented by Lundblad (28) in connection with his investigations of the podzols in the coniferous forests and degraded brown earths in the beech forests of southern Sweden. He points out that the horizon of accumulation with orterde formation in the podzols contains a higher amount of gel than any horizon in the profile. Another fact brought out in his work is that the inorganic gel content of ortstein formation is relatively small when compared with the organic colloids.

A discussion of the work of Tamm and Lundblad as well as of the more important investigations on the ortstein formation is given by Stremme (47). He quotes van Bemmelen, who designated ortstein "as a cementing of the sand particles with colloidal humus, silicic acid, aluminum and iron oxide complexes, and some clay fractions."

According to Aarnio (2) the process of ortstein formation is to be identified with the movement of the sesquioxides and humus from the surface horizons into the lower ones. The iron and aluminum move as sols protected by the humus, by the silicic acid sols, as well as by the cations Ca, Mg, K, Na, and the anions SO_4, PO_4, and CO_3. If there is little humus, iron ortstein, poor in humus, forms. With large amounts of humus, humus ortstein, poor in iron, forms. The precipitation of sesquioxides is homogeneous in sandy soils. In loam and clay soils they precipitate in cracks and tracks of roots.

The relation between the parent material and ortstein formation has been investigated by Münst (34) and Helbig (22).

Stremme (47, p. 134) discusses the influence of ortstein formation and podzolization on forest growth and the relationships between podzolization and type of vegetation. He quotes Hazard (21), who shows that under certain conditions ortstein is an asset to the physical conditions of the soil. He also quotes Hausrath (20) in this connection. Tamm (48) concludes that podzol and ortstein formations are of no great significance from the forestry standpoint.

Emeis (10) attempted to approach the subject of ortstein formation experimentally. He filled several cylinders with quartz sand, added the various constituents which make up the ortstein, and percolated daily a humus extract through that. He succeeded in forming a humus-iron ortstein by the reaction of the sesquioxides, humus, and lime.

Filatov (11) passed colloidal solutions of iron hydroxide through columns of quartz sand with intermediate thin layers of fine quartz (0.05–0.001 mm.). He found that only the fine quartz became colored with iron. Intermediate layers of finely ground minerals (orthoclase, biotite) exhibited a still greater retentive power for the iron.

A discussion of hardpan or ortstein is presented by Hilgard (23, p. 184). He correlates its formation with the deposition of iron, clay, and humus.

Skeen (42), who defines hardpan as "that stratum found at varying depths below the surface composed of 'clays' and sands more or less cemented by precipitated Fe, Al, and sometimes organic compounds," correlated hardpan formation with the hydrogen-ion concentration of the medium. Whenever the pH of the clay soil he was working with was 4.8, hardpan was found. He conducted experiments showing how $Fe(OH)_3$ precipitated on kaolin at that particular pH.

In a second paper Skeen (43) advances a theory on the formation of hardpan in acid clay soils. If the reaction of the upper layers of the soil is acid enough to bring into solution Fe and Al, hardpan might form.

The limited observations of Skeen should not have been generalized. As a matter of fact almost all the soils in the podzol zone, except where the parent material is limestone, are sufficiently acid to dissolve some Fe and Al and still not all podzols, even of clay texture, have an ortstein or hardpan layer. It is well established now that podzols and ortstein formation do not run parallel.

Summarizing the work of Western European and Russian investigators on ortstein formation, Glinka (18, p. 325) points out that

> . . . . horizon A_2 becomes impoverished of bases and sesquioxides, when compared with the parent material, and the ortstein becomes enriched with the sesquioxides and manganese, but not always with bases, except magnesium. Ortstein decomposes more rapidly than the parent material in HCl solution. The solubility of alumina in ortstein increases very markedly.

Poluinov (36, 37) investigated mineralogically and chemically the new formations in ortstein. He found a mineral of the polygorskite type. It is a magnesium aluminum silicate and apparently this is the source of magnesium which is so frequently encountered in ortstein.

Gemmerling (14) demonstrated the presence of free aluminum hydroxide in ortstein concretions, which is in accord with the theory of Gedroiz (13) that in the podzol soils some portion of the aluminum silicate nucleus is decomposed.

At times the ortstein formation appears in the profile as narrow winding bands of a dark brown iron-like color. They were studied by Visotzkii (53), who designated them as pseudofibers. They are encountered primarily in weakly podzolized soils.

A review of the problem of pan formation is given by Jones and Willcox (25). They discuss some of the earlier theories and present some experimental evidence on the process of pan formation. Extractions were made with dilute solutions of tartaric or oxalic acid on soils from several podzol profiles. The extract from the A horizon was filtered, a portion sampled for analysis and the rest used for the extraction of the soil from the B horizon. Again the extract was filtered, sampled for analysis, and the remainder used for the extraction of the soil from the C horizon. The data obtained show that the sesquioxides go into solution in the A horizon and precipitate in the B horizon. It is suggested that the sesquioxides enter

. . . . into the electro-negative portion of the molecule, since soil organic acids consist largely of hydroxy acids and these acids dissolve the sesquioxides to form salts of the type $Fe_2R_3 \cdot Fe_2O_3$. These compounds are then leached through the soil in solution and are ultimately precipitated as basic salts, thus giving rise to a zone of sesquioxide accumulation and finally to a pan

Another type of ortstein formation is the concretions which appear at the bottom of the A_2 and on the top of the B horizon. They contain variable amounts of humus, iron, and sometimes manganese. The humus content in the concretions is greater than that in the surrounding soil material. Usually concretions are found in clay podzols.

Some pedologists link the process of podzolization with ortstein and concretion formation. Tumin (50) does not share this view. According to him:

Ortstein is encountered on sandy parent materials only; on loams there is no ortstein, but concretions (iron and manganese) in the form of grains or complexes of grains. And even on sands ortstein is not always found. The same might be said about concretions on loams. Thus ortstein and concretions do not accompany all podzolized soils, except several of them which form under certain conditions.

It is of interest that ortstein is always found at the boundary between horizons A and B. This is not true for concretions, which are to be found in all horizons. In the southeastern portion of the zone (on the sands) ortstein is found also in the depressions. In the northwestern portion ortstein gradually appears as we go from the deep depressions to the level topography.

In general the facts of ortstein and concretion deposition indicate that they are formed under conditions of change from deoxidation to oxidation processes in the soil.

GLEY FORMATION

In Russia the popular understanding of gley, according to Visotzkii (52), is "a more or less compact, sticky loam or clay parent material, which is not, however, as sticky as the usual loam or clay, frequently with a more or less clearly pronounced light greenish blue tinge."

Gley formation is found in marshes and under conditions of a high water table. The gley horizon is generally water-logged, except when the water table recedes. In this horizon, therefore, anaerobic conditions prevail, favor reducing reactions, and minimize leaching effects. Besides, the ground waters rise by capillary forces and enrich the gley horizon with bases, imparting to it an alkaline reaction.

The simultaneous downward and upward movements of the substances in solution bring about a unique condition with respect to the iron. The anaerobic state is inducive to reducing reactions and the insoluble iron compounds become soluble and move downward. At the same time the rise of substances in solution by the capillary forces brings back some iron to a point where it might come in contact with the air and precipitate. We thus find an ocherous layer on the top of the gley horizon. This is probably the chief factor in the process of bog iron formation. While the upper layer of the gley horizon becomes enriched with iron, the lower layer becomes impoverished of iron. It

is in this layer of the gley horizon where we find the mottling effects with the characteristic gray bluish-green tinge of the material.

In many respects, the process of ochre formation is similar to that of the rising of salts in alkali soil formation. This has been pointed out by Visotzkii (52), who was probably the first one to study gley formation.

Within the podzol zone, especially in the northern belt of it adjoining the forest tundra belt, gley formation is not uncommon. This does not exclude

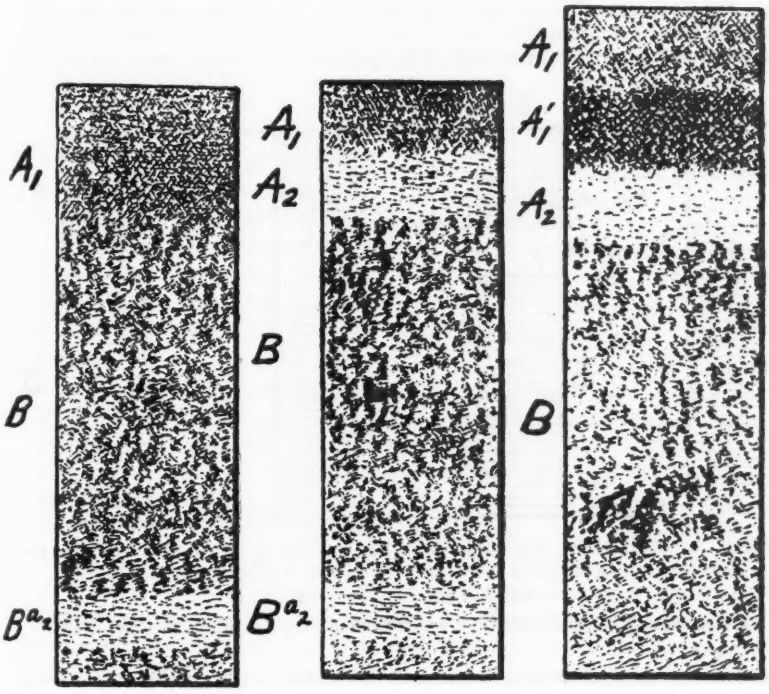


FIG. 1 FIG. 2 FIG. 3

FIG. 1. WEAKLY PODOZOLIZED SOIL WITH A BLEACHED HORIZON BELOW B
FIG. 2. A PODZOL WITH A BLEACHED HORIZON BELOW B
FIG. 3. A PODZOL WITH A DARK COLORED SUBHORIZON A_1'

the existence of gley formation in other soil zones, since it is not a climatogenic formation but a hydrogenic. Indeed Visotzkii (52) points out the presence of gley formation in the southeastern Precaspian steppe.

Gley formation has been studied primarily in the podzol zone and has therefore been associated with this zone. Whenever gley formation is found on a podzol soil, it is the C or B horizons which undergo the respective changes. The A_2 horizon remains intact, i.e. the rising waters do not reach this horizon.

Frosterus (12) in his work on the podzols with clay as parent material and a high water table discusses the question of gley.

An extensive study of soils with a gley horizon in the podzol zone has been made under the direction of the late Glinka by Zavalishin (57). His observations are summed up as follows:

The gley horizon appears in the form of a sandy or clay material of a light-gray or gray color with a bluish, blue, or sky-blue tinge. The color is not uniform; it depends on the intensity of gleying and on the mechanical composition of the material. Usually the gray blue background is mottled with large red spots and veins. Usually these spots are associated with the cracks and root paths and they are more frequent in the clay varieties. The spots around the roots may be of two kinds: if the material is not strongly gleyed and there is

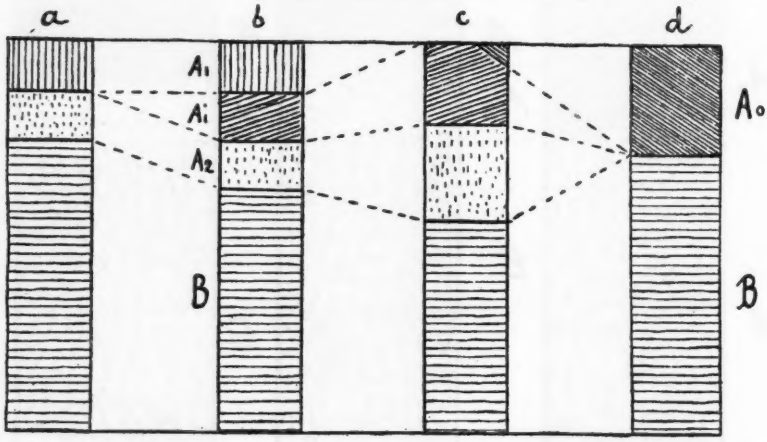


FIG. 4. A DIAGRAMMATIC PRESENTATION OF THE INFLUENCE OF MICRO-RELIEF ON THE GRADUAL REPLACEMENT OF THE A_1 HORIZON BY THE A_1' SUBHORIZON AND FINALLY BY THE A_0 HORIZON (PEAT FORMATION)

a, level place; b, slight depression; c, a slightly deeper depression; d, a peat depression.

decomposed organic substance in the root path, then we have a light gray-bluish gley formation with a reddish band on the outside. If, on the other hand, the gleying has proceeded very far and the root path is nothing more than a tube through which air passes, then a red ring forms around it on a light-gray bluish background. When the gleying is very strong then the parent material is of a homogeneous gray-blue coloration without any spots or veins. Gley horizons, especially sandy, at times resemble podzols; the bluish tinge and the red spots identify it, however, as gley.

Usually the gley horizons are without structure, more or less compact, sticky, smeary, and appear to be more clayey than the adjoining parent material. A suspension of gley formation does not settle out and it is highly dispersed.

The humus content is higher in the upper layer of the gley horizon than in the lower. The solubility of the humus increases with an increase in gleying. With that, the reducing property of the gley increases and this in turn influences the reducing reactions with respect to the iron compounds.

Zavalishin presents a lot of data which seem to indicate that the gley horizon, designated as G, either approaches neutrality or is neutral or alkaline. With respect to saturation with bases the gley horizon differs but little from the parent material. It varies depending on the composition of the ground waters. One thing is certain: it contains a higher content of replaceable magnesium and slightly less calcium. There is also a slight increase in silica. The presence of reduced iron compounds in the gley has also been demonstrated.

From what has been said, it may be inferred that *gley formation on podzols indicates the termination of the podzol process of soil formation and the inauguration of the marsh or tundra types of soil formation.*

FOREST-GRAY AND BROWN EARTHS

Within the borders of the large climatogenic zone of podzols two other types, or rather subtypes, have been recognized: (a) the gray-forest and (b) the brown earths, known as the "Braunerde" of Ramann.

Forest-gray soils.—The forest-gray soils develop under conditions of deciduous forests. In a way they are a transition type between the chernozem and the true podzols. A striking characteristic of the forest-gray soil profile is the gray color of the A horizon which turns into brownish with depth. Chemically these soils differ but little from the true podzols. Both are acid with an increase in the intensity of acidity from the surface down to horizon B where the acidity decreases. The base exchange capacity is lowest in A_2, the latter being the poorest in colloids. With depth the capacity for base exchange increases because of the illuviation of the colloids. In the process of its formation some of the silicates in the surface horizon suffer disintegration and decomposition whereby some silica separates out on the nut-like structural units of these soils. (Dokuchaev in his time described the gray forest soils as "nutty").

Whenever the forests advance on the steppe, the soil becomes degraded. It loses its original morphology; a translocation of the humus and mineral substances takes place in a similar manner as in the podzols and the soils approach the morphology, composition, and make-up of the forest-gray soils. The podzol process of soil formation sets in as soon as the forest cover is capable of keeping the surface horizon moist and thereby favoring the leaching reactions by the percolating rain waters.

A discussion on the process of podzolization in the forest-gray soils is presented by Il'in (24). He takes up the question raised by Glinka (18) about the process of podzolization being secondary in the forest-gray soils. He links the secondary nature of the podzolization process on the forest-gray soils with the concept of degradation.

A comprehensive review on the genesis and occurrence of forest-gray soils is presented by Tyurin (51) and Levchenko (27).

Brown earths or "Braunerde" of Ramann.—According to Ramann (40)

> . . . . the brown earths develop under the influence of a temperate climate which fluctuates greatly; some years are wet and others dry, so that the leaching of the soil is very much greater

at some times, very much less at others. The rainfall is not sufficient during the warm season to form seepage water in soils which are covered with vegetation. In warm and dry years slightly arid conditions prevail, so that the effects of the ascent of the ground water are seen. This is mainly evidenced by the soil water being enriched in calcium carbonate, though deposits of calcium carbonate in appreciable quantities are rare, or are only found in soils having an abundant water supply as in the loess. Leaching preponderates in most of the brown earths; the soluble salts and the earthly carbonates are washed out, while phosphates and the sesquioxides are retained in the soil. . . . .

In no other soil formation does the parent rock exercise such a large influence as in the brown earths. . . . . The soil has normally a neutral or slightly alkaline reaction; hence readily dispersed humus bodies are not found.

A series of brown earth profiles are described by Glinka (15). He considers them as a variety in the podzol zone, and as a condition for the formation of the "Braunerde" he lays down the prerequisite of lime carbonate in the parent material.

In another place Glinka (17) states:

All the participants of the excursion [in connection with the soil conference in Hungary] who happened to study the brown earths in their respective countries have agreed with me that the brown earths examined by us represent one of the varieties of the podzol type of soil formation on carbonate loams. It is to be noted that the brown soils in most cases contain carbonates in the lower horizon.

In still another place Glinka (18, p. 343) expresses the idea that these soils are of a transition type; "the brown earths of Western Europe represent, so to speak, the last stage of the podzolized type of weathering; they are transitory to the more southern yellow and red earths."

Some brown earths in Crimea have been described by Antipov-Karataev and his collaborators (3). They found no effervescence in the B horizon. Stebut (46) has recently contributed to the problem of brown earths.

Prasolov (38) agrees with Glinka that the brown earths are a transition stage from yellow and red soils of the southern regions into podzols.

It is of interest to note in connection with the process of brown earth formation that a number of investigators who described brown earths—Tamm (48, 48a), Lundblad (28), and Prasolov (38)—invariably associated them with beech forests. A glance at the analyses of the ash constituents of beech forest litter shows that the per cent of ash is high in beech (5.57 per cent in beech against 1.46 per cent for pine) and the ash contains high amounts of CaO [2.46 per cent against 0.59 per cent for pine; the analyses are taken from Glinka's (18 p. 30) work]. All of the CaO and the other bases complete a definite cycle which in its turn has an influence on the process of soil formation. It comes to the plant from the horizons of root distribution and the greatest portion is redeposited in the humus accumulative horizon A_0 to become mineralized and leached out. With the high amounts of ash constituents and especially Ca in beech litter, the replenishment of leached bases is high and thus a hindrance to the process of podzolization.

GENERAL DISCUSSION

With Tumin's (50) presentation of the process of podzolization as the central idea, a puzzling element appears, namely, that, according to him, the process of podzolization is more pronounced in the soils with a heavier texture than in those with a lighter texture. It is to be remembered that Tumin's contention, based on his wide experience and numerous investigations is applicable to the central belt of the podzol zone. He points out that the loam soils in this belt are true podzols whereas the sandy loams are merely podzolized. No explanation is offered by Tumin for such a behavior. It would seem that on the lighter soils the percolation effects should be more clearly expressed than on the heavier soils. On the other hand, one might expect quantitatively a more intensive reactivity in the heavier soils, which contain a larger supply of internal factors of podzolization, especially organic matter which furnishes the decomposition products of microbial and chemical activity, such as carbonic, nitric, sulfuric, and other inorganic and organic acids and colloids.

It seems that the process of podzolization is to a large extent intimately related to the speed of decomposition and quantity of organic matter. A too rapid destruction of the organic matter depresses the reactivity efficiency of the split products, since under such conditions the organic acids produced are usually decomposed to the so-called mineralized state. The result is that the rôle of the organic acids is reduced to a minimum.

It is very probable that such are the dynamic forces in the process of laterization whereby the residual mineralized cations (especially the monovalent as well as the H ions) link in some manner with the SiO_3 anion from the Al and Fe silicate complexes and move downward leaving behind the sesquioxides. Since the organic complexes are completely mineralized the sesquioxides have no humates to combine with. In soils undergoing the process of podzolization some of the bases and of the sesquioxides combine with the humates and move downward to enter again into a reaction (depending on a number of factors, especially the pH) with some SiO_3, forming new Al and Fe silicate complexes. The work of Mattson (29, 30) at this station on the behavior of the anions with respect to the sesquioxides in acid and alkaline media, or rather on the acid and alkaline side of the isoelectric precipitates, promises to discover the fundamental principles of this process.

In the belts north of the true podzol belt the organic matter, as a rule, does not undergo such rapid decomposition and does not therefore mineralize so fast. Under such conditions the percolation element of podzolization dominates the process and, of course, the lighter soils are more thoroughly and efficiently leached. The result is that in these belts the lighter soils become more rapidly podzolized than the heavier soils.

The considerations presented open the question of the rôle of organic matter in the process of podzolization from an entirely new angle. We are not concerned so much now with empirical studies of the early investigators on the

relative importance of the hypothetical crenic and apocrenic, and humic acids in the soil profile. We are concerned in learning the condtions under which the various organic substances which form humates behave in one way or another. The work of Mattson (29, 30) on the isoelectric precipitates of the sesquioxides under various conditions of pH and electrolyte content and the anion exchange relation with respect to the humates offers an approach to the study of organic matter distribution in the soil profile of the podzol zone. A study of a large number of cases of carefully sampled profiles would be necessary before the existing conditions in the soil might be correlated with Mattson's theoretical deductions.

From this point of view a survey of the organic matter distribution in the profile of the soils along the Atlantic slope from Maine to Florida would give us valuable information on the geographic distribution of the process of podzolization. It would take in the true podzols, the podzolized soils, and the transitional brown earths (perhaps also some forest-gray soils) blending into the yellow earths, red earths, and finally laterites.

Some of the points presented in this paper will be taken up and illustrated in a forthcoming paper dealing with the work done on some of the podzol and podzolized soils of New Jersey.

SUMMARY

A historical review of the subject is given.

The theories on the process of podzolization as presented by some of the important Russian investigators and others have been reviewed and differences pointed out.

The relation of ortstein or pan formation to the process of podzolization and the mode of its formation and occurrence have been discussed.

Gley formation as related to the process of podzolization has been discussed. It is pointed out that gley formation on podzols indicates the termination of the podzol type of soil formation and the inauguration of the marsh or tundra type.

The question of the relation of forest-gray soil to podzols has been touched upon.

The position of brown earths or "Braunerde" in the zone of podzolization, their relation to the type of forest vegetation, and the process involved have been discussed and analyzed.

A somewhat new aspect of the rôle of organic matter in the process of podzolization has been suggested and discussed. It seems that the speed of decomposition and mineralization of organic matter and the relation of the humates in the anion exchange reactions as worked out by Mattson with the isoelectric precipitates have an important bearing on the variations in the process of podzolization throughout the different belts of the podzol zone.

REFERENCES

(1) AARNIO, B. 1913 The precipitation of iron in podzol soils. *Internatl. Mitt. Bodenk.* 3: 131–140.

(2) AARNIO, B. 1915 The precipitation of the oxides of iron and aluminum from sandy and gravelly soil of Finland. *Pochvovedenie* 17 (2): 1–50.

(3) ANTIPOV-KARATAEV, I. N., ANTONOVA, M. A., AND ILLUVIER, V. P. 1929 The soils of the Nikitskii gardens. Otdel Pochvovedeniya Gosudarst. *Inst. Opuit. Agron. Bul.* 4: 1–241.

(4) BOGOSLOVSKII, N. A. 1902 From observations on the soils of Western Europe. (Russian). *Pochvovedenie* 4: 357–368.

(5) DETMER, W. 1871 Die natürliche Humuskörper des Bodens und ihre landwirtschaftliche Bedeutung. *Landw. Vers. Sta.* 14: 298–300.

(6) DOBROVOL' SKII, M. 1900 The nature and origin of podzols according to our present knowledge of soil science. (Russian). Materialui po izuchenii russkikh pochv. *Bul.* 13: 1–48.

(7) DOKUCHAEV, V. V. 1877 On the Normal Deposits of Chernozem (Russian). St. Petersburg.

(8) DOKUCHAEV, V. V. 1879 Abridged historical account and critical examination of the principal soil classifications existing (Russian). Trans. *St. Petersburg Soc. Nat.* 10: 64–67.

(9) DOKUCHAEV, V. V. 1883 Russian Chernozem (Russian). St. Petersburg.

(10) EMEIS, C. 1908 Die Ursachen der Ortsteinbildung und ihr Einfluss auf die Landeskultur in Schleswig-Holstein. *Vereinsblatt des Heidekultur-Vereins für Schl.-Holstein*, 9–20. [Quoted from Zakharov (56)].

(11) FILATOV, M. 1922 On the problem of the genesis of ortsand. (Russian). Russkii pochvoved, no. 1–3.

(12) FROSTERUS, B. 1913 Soil formation in clays of humid regions. *Internatl. Mitt.-Bodenk.* 3: 99–130.

(13) GEDROIZ, K. K. 1929 On the Absorbing Properties of Soils. State Publishing House "Novaya Derevnya," Moscow-Leningrad.

(14) GEMMERLING, V. V. 1922 Some data which characterize podzol soils. (Russian). Russkii pochvoved, no. 4–5.

(15) GLINKA, K. D. 1911 On the so-called brown earths. *Pochvovedenie* 13: 17–48.

(16) GLINKA, K. D. 1924 Disperse System of Soils (Russian). Leningrad.

(17) GLINKA, K. D. 1926 The conference of the third commission of the International Society of Soil Science in Hungary. *Pochvovedenie* 21: 108–118.

(18) GLINKA, K. D. 1927 Pochvovedenie (Soil Science). A Textbook. "Novaya Derevnya," Moscow.

(19) GLINKA, K. D. 1928 The great soil groups of the world and their development. Translated from the German by C. F. Marbut. Mimeographed by Edwards Bros., Ann Arbor, Mich.

(20) HAUSRATH, H. 1907 Der Deutsche Wald. Leipzig.

(21) HAZARD, J. 1907 (?) Bericht über seine zu Anfang des Sommers 1907 behufs bodenkundlicher Untersuchungen nach Nordwestdeutschland unternommenen Reise [Unveröffentlicht: Quoted from Stremme (47)]

(22) HELBIG, M. 1909 Über Ortstein im Gebiete des Granits. *Naturw. Zeitschr. Forst u. Landw.* pp. 1–8. (Quoted from Stremme).

(23) HILGARD, E. W. 1906 Soils. Macmillan Co., New York.

(24) IL'IN, R. S. 1927 On the problem of the border lines of the podzols and forest-gray soils. *Pochvovedenie* 22 (3): 5–26.

(25) JONES, H. TREFOR, AND WILLCOX, J. S. 1929 Studies in soil genetics: I. *Jour. Soc. Chem. Indus.* 48: 304T-308T.

(26) KOSSOVICH, P. 1910 The soil forming processes as the basis for a genetic soil classification. (Russian). *Zhur. Opuit. Agron.* 11: 679–703. [See also his book: Osnovui ucheniya o pochve (1911).]

(27) LEVCHENKO, F. I. 1930 Gray soils of the forest steppe in the European part of the U. S. S. R. *Pochvovedenie* 25 (3): 49–72.

(28) LUNDBLAD, K. 1924 Properties and degeneration of the soils derived from brown earth types in southern Sweden. *Meddel. Statens Skogsförsökanst.* (Sweden) 21: 1–48. (German Summary: 45–48).

(29) MATTSON, SANTE 1930 The laws of soil colloidal behavior: III. Isoelectric precipitates. *Soil Sci.* 30: 459–495.

(30) MATTSON, SANTE. 1931 The laws of soil colloidal behavior: IV. Isoelectric precipitates. *Soil Sci.* 31: 57–77.

(31) MULDER, G. J. 1840 Untersuchungen über die Humussubstanzen. *Jour. Prakt. Chem.* 21: 203–240, 321–370.

(32) MULDER, G. J. 1840 Untersuchunger über die humusartige Materien. *Liebig's Ann. Chem. u. Pharm.* 36: 243–295.

(33) MÜLLER, P. E. 1887 Studien über natürlichen Humusformen. Berlin.

(34) MÜNST, M. 1910 Ortsteinstudien im oberen Murgtal. *Mitt. Geol. Abt. Kgl. Württenb. Stat. Landesamtes* (Stuttgart) 8: 30. (Quoted from Stremme).

(35) NEUSTRUEV, S. S. 1930 The elements of the Geography of Soils. (Russian). State Agricultural, Leningrad, Moscow.

(36) POLUINOV, B. B. 1915 Secondary minerals of ortstein horizons. (Russian). Izvestia Dokuchaev. Pochv. Komit. no. 2.

(37) POLUINOV, B. B. 1927 The sands of the Don region. (Russian). Reprint from *Trudui pochvennogo instituta imeni Dokuchaeva*, part 2: 1–198.

(38) PRASOLOV, L. I. 1929 The brown earths of Crimea and the Caucusus; Priroda no. 5. (Quoted from Proc. *Internatl. Soc. Soil Sci.* (1930) 5 (2): 125).

(39) RAMANN, E. 1905 Bodenkunde, ed. 2. Berlin.

(40) RAMANN, E. 1928 The evolution and classification of soils. (English translation by C. L. Whittles). W. Heffer and Sons, Cambridge, England.

(41) SIBIRTZEV, N. J. 1909 Pochvovedenie. (Soil Science).

(42) SKEEN, JOHN R. 1925 A critical pH for the formation of hardpan in acid clay soils. *Soil Sci.* 20: 307–311.

(43) SKEEN, JOHN R. 1927 Effects of some electrolytes on kaolin and the probable elation to the soil. *Soil Sci.* 23: 225–242.

(44) SMIRNOV, V. P. 1912 Experimental data on podzol formation. *Ezhegod. Geolog. i Miner. Russii* 14: 206–210.

(45) SPRENGEL, K. 1837 Die Bodenkunde oder Lehre vom Boden nebst einer vollständigen Einleitung zur chemischen Analyse der Ackererde. Leipzig.

(46) STEBUT, A. 1929 Die "Braunerde." A summary of a paper read before the 5th Commission. Intern. Soc. of Soil Sci. *Proc. Internatl. Soc. Soil Sci.* 4: 209.

(47) STREMME, H. 1926 Grundzüge der praktischen Bodenkunde. Gebrüder Borntraeger, Berlin.

(48) TAMM, O. 1920 Soil studies in the needle forest region of northern Sweden. *Meddel. Statens Skogsförsöksanst.* (Sweden.) 17: 49–300. (German Summary: 279–300).

(48a) TAMM, O. 1930 The brown forest soils in Sweden. *Ztschr. Schwed. Forstvereins* 28: 1–41.

(49) TUMIN, G. M. 1911 Podzolization and leaching of bases. (Russian). *Zhur. Opuit. Agron.* 12: 1–19.

(50) TUMIN, G. M. 1912 A survey of the general character of soil morphology and its changes within the zones. (Russian). *Zhur. Opuit. Agron.* 13: 321–3531

(51) TYURIN, I. V. 1930 Genesis and classification of forest-steppe and forest soils. *Pochvovedenie* 25 (5): 104–141.

(52) VISOTZKII, G. N. 1905 Gley. *Pochvovedenie* 7: 291–327.
(53) VISOTZKII, G. N. 1913 Soil-forming processes in sands. (Russian). Izvestia Russk. Geograph. Obshches, v. 47. Quoted from Neustruev (35).
(54) WARRINGTON, R. 1900 Lectures on some of the physical Properties of the Soil, 25, 28. Oxford, England.
(55) WILLIAMS, V. R. 1927 Obshchee zemledelie s osnovami pochvovedeniya. (A text-book on "General Agronomy and the Fundamentals of Soil Science") Moscow.
(56) ZAKHAROV, S. A. 1910–1911 On the problem of the influence of the macro and micro relief on the soils in the podzolized region. *Pochvovedenie* 12 (1910): 339–366; 13 (1911): 49–72.
(57) ZAVALISHIN, A. A. 1928 Some observations in the study of soils with a close gley horizon. (Russian). Pamyati. K. D. Glinki. (K. D. Glinka: A memorial). Leningrad. Selsko-Khoz. Inst. 45–90.

BOOK REVIEWS

Handbuch der Pflanzenernährung und Düngerlehre, vol. II. By F. HONCAMP. Julius Springer, Berlin, 1931. Pp. xii + 919, figs. 285.

The entire volume is devoted to the subject of manures and fertilizers and their use. In dealing with so extensive a field of science and practice the editor and his associates were evidently compelled to condense much of the material treated under nine general topics. These consist of manures and manuring; natural manures; artificial manures; the use of artificial manures; the manuring of cultivated crops; the use of manures in forestry; the manuring of marsh and heath soils; the manuring of ponds; and manuring, manures, and plant protection.

The term "manures" is used here in its broadest definition to include animal waste products (livestock manures), industrial by-products (tankage, cotton-seed meal, basic slag, etc.) and chemical compounds manufactured specifically for increasing the supply of available plant food for crops. In the United States, on the other hand, the terms "manures" and "fertilizers" are employed to describe animal manures on the one hand, and industrial by-products (organic and inorganic) and synthetic compounds on the other.

The historical review of the subject is short, but adequate. The natural manures as dealt with by the authors include human waste products, green manures, composts, and stable and barnyard manure. Under the general topic *artificial manures* we find a discussion of potash, lime, phosphates, nitrates and ammonium salts, cyanamide, urea, and of salts and mixtures containing two or more of the major plant nutrients. The organic and inorganic waste and by-products used in commercial fertilizers are also described more or less fully. Some space is devoted to a discussion of *plant stimulants*.

The fertilization of specific crops in the groups of root and tuber crops, cereals, legumes, oil and fiber crops, vegetables, grapes and tree fruits, hops and tobacco is discussed within a space of about 200 pages. The fertilization of the soil in forest nurseries and in the forest itself offers much that is suggestive. No less interesting is the discussion of the methods employed toward increasing the supply of food for fish-culture. Materials containing lime, potash, phosphoric acid, and nitrogen are all considered as means toward increasing in ponds and lakes the supply of algae and of other food for fish. The use of chemical fertilizers in their relation to diseases, insect enemies, and parasites of crops; and likewise their value in combating weeds are dealt with more or less adequately. Altogether, the book is a distinct and valuable addition to our reference material on manures and fertilizers.

Die Schlämmanalyse. By HERMANN GESSNER with introduction by Georg Wiegner. Akademische Verlagsgesellschaft M.B.H., Leipzig, 1931. Pp. vii + 244, figs. 102, and 1 table.

This is the volume 10 of the series "Kolloidforschung in Einzeldarstellungen" founded by Zsigmondy and edited by Freundlich.

The author has rendered a real service in systematizing and in outlining in a helpful way the recent, as well as the older, information on soil colloids. After presenting the theoretical considerations on which the mechanical analysis of "fine earth" is based, he enters into a discussion of the various methods, apparatus, and devices employed for the purpose. His familiarity with the literature is apparent and his references are well chosen. In describing the procedures employed in the laboratory he again shows himself to be master of practice, as well as of theory. The book should prove to be a valuable aid to the teacher and a source of fruitful information for the student.

Entwicklung der Bodenkartierung Landwirtschaftlicher Betriebe und die Möglichkeiten Ihrer Praktischen Leistung. By W. TASCHENMACHER. Max Weg, Leipzig, 1930. Pp. 78, illus. 4, charts 1.

It is noted by the author that the mapping of farm land was not begun until the nineteenth century and that the first valuable soil map to become widely known was prepared in 1868. Soil classification and mapping acquired significance only in comparatively recent times and largely because of their direct relation to problems of soil management. The first 35 pages of the book are devoted to a discussion of different systems of soil classification, namely, those based on geology, agricultural chemistry, and internal soil characteristics. In part II of the book (pp. 44–67) the soils of the estate Krzyzanki, representing an area of 302 hectares, receive especial consideration from the soil management point of view. Part III is devoted to the mapping of soils of individual farms as a distinct aid toward their effective utilization agronomically, as well as economically.

Australian Rain-Forest Trees. By W. D. FRANCIS. Anthony James Cumming, Brisbane, 1929. Pp. xi + 347, 213 full-page, half-tone illustrations 25 text figures, 1 rainfall map.

We are told by the author that:

> Rain forests consist of closely spaced, dense vegetation composed mostly of trees, shrubs, vines and herbaceous plants. Sometimes they are so dense that is difficult or impossible to penetrate them without the use of cutting tools. . . . . In rain forests, especially in those of a luxuriant character, the trees harbour numerous plants known as epiphytes. The commonest epiphytes in rain forests are ferns, orchids, and lichens. . . . . Very prominent among the conditions which accompany rain forests in Australia is a high rainfall. The writer has remarked that the luxuriant rain-forest areas of Queensland have an average annual rainfall approximating or exceeding 60 inches.

The reader will find in the book a wealth of carefully arranged information on the nature and distribution of rain forests and their relationship to rainfall, geology, and soils. The topics specifically dealt with include the height and size of trees, buttresses, flanged stems, corrugated woody cylinders, the bark, wood, and leaves of Australian rain-forest trees. The families are briefly described and a key is suggested as a means of facilitating identification. Pages 42–340 are given over to descriptions and illustrations of the species.

J. G. LIPMAN.